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Intensity Scale Sensitometer

Swaminathan Kalyanam

INTENSITY SCALE SENSITOMETER

by

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in the School of Photographic Arts and Sciences in the College of Graphic Arts and Photography of the Rochester Institute of Technology

June, 1976

Thesis adviser: Dr. G.W. Schumann

Certificate of Approval--Master's Thesis

School of Photographic Arts and Sciences
Rochester Institute of Technology
Rochester, New York

CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's Thesis of

Swaminathan Kalyanam

with a major in Photographic Science and Instrumentation has been approved by the Thesis Committee as satisfactory for the thesis requirement for the Master of Science degree at the convocation of June, 1976

Thesis Committee: ______________________
Thesis adviser

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Graduate adviser

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Director or designate

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INTRODUCTION

The sensitometers for testing the characteristics of photographic film can be broadly divided into two categories: intensity-scale and time-scale. Intensity is varied in the intensity-scale sensitometers, and time is varied in the time-scale sensitometers to produce the modulation in exposure.

The time-scale sensitometers have the drawback that to produce the exposures obtained in practice, the time of exposure has to be varied so widely that Reciprocity Law will no longer hold good. Secondly in photographic practice, the time of exposure is fixed and the intensity of illumination in the object being photographed varies from point to point. Thus, an intensity-scale sensitometer reproduces conditions more similar to what is obtained in practice than the time-scale sensitometer. The disadvantages of the intensity-scale sensitometers are their complexity and higher cost.

A few years ago, 3M Company, St. Paul, Minnesota began to design and build an intensity-scale sensitometer. Some components were designed and ordered. The project was not, however, completed. The ordered parts were sent to Rochester Institute of Technology, Rochester, New York, so that the rest of the instrument could be designed and the apparatus constructed. The parts received from 3M Company were: Tungsten Iodide and Pulsed Xenon arc lamps, Cylindrical achromat lens, Shutter assembly, Control cabinet and Electrical components.

Objective

The main objective of the project was to design the sensitometer using the components already available, fabricate or purchase the components needed, and assemble all the parts to form a sensitometer for exposing films used in the Graphic arts industry to Tungsten Iodide or Xenon arc light sources.

WORKING PRINCIPLE OF THE SENSITOMETER

Light from a set of lamps is incident on a diffuse reflecting surface R as shown in Fig.1, page 4. A diaphragm D with rectangular slots cut in it in a stepped manner is placed next to the reflector. The slot contour illuminated by the reflector forms the object for the cylindrical lens L which images it on the film plane F. The shutter assembly S consists of a slit controlling the overall intensity of the object incident on the lens, and a shutter release to take timed exposure of the test film. The image of the diaphragm formed by the lens on the film holder F will be a series of stepped intensities. The incremental intensity from step to step depends on the relative dimensions of the steps in the diaphragm. The image formed by exposure on a photographic film strip in the film holder after processing will be a series of density steps.

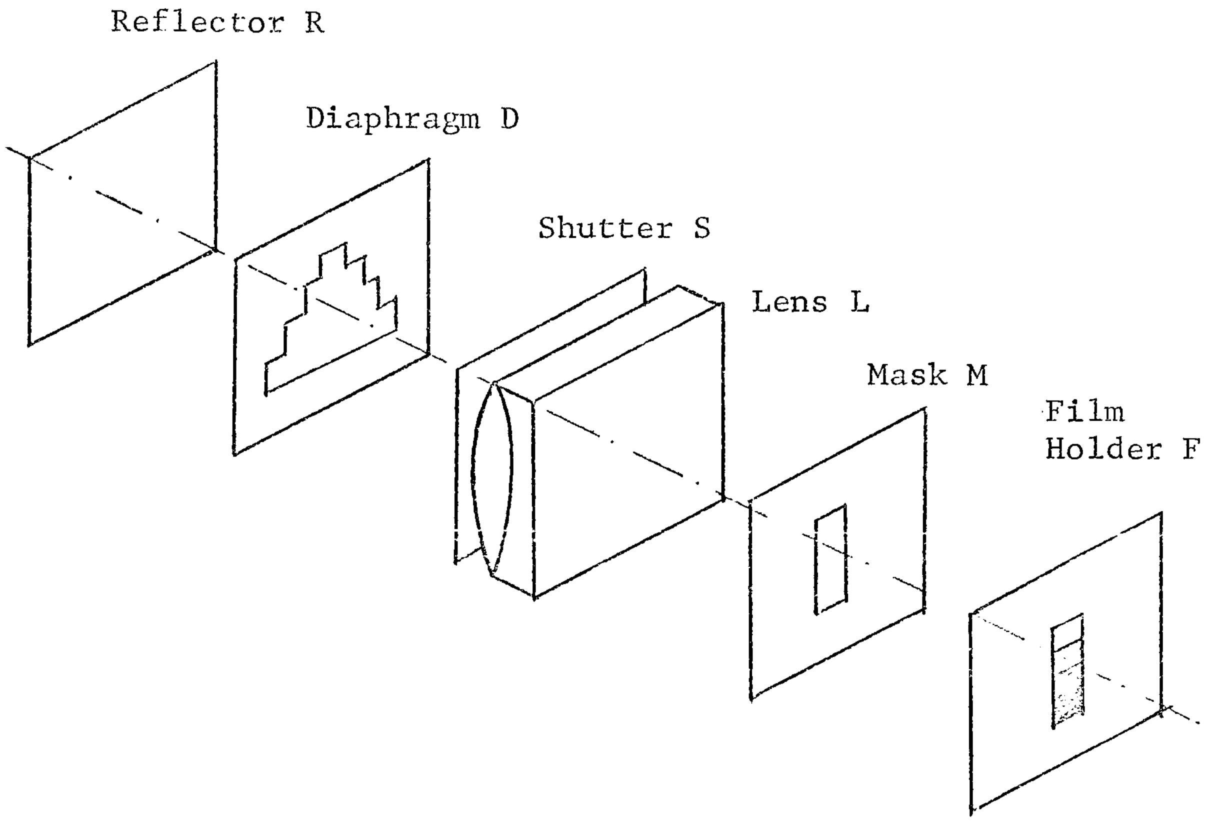


Fig.1 Working principle of sensitometer

REQUIREMENTS OF A SENSITOMETER

1. The exposure range obtained in the test film strip should be wide enough to cover the minimum and maximum exposures encountered in the general practice.

2. The time of exposure should be adjustable within the limits normally obtained in practice.

3. The overall intensity of illumination falling on the test film should be adjustable.

4. The operating time to expose the test film strip should be reasonably short.

5. The results should be accurate and reproducible.

6. The intensity and spectral distribution of the source of light should be constant.

7. Dust should be excluded from the apparatus.

8. The sensitometer should occupy as little room as possible.

The intensity-scale sensitometer meets all the requirements expected for good sensitometric work. The commonly used sensitometer in industry for testing Graphic art films utilizes a step tablet to produce variations in the intensity of light falling on the test film strip. The intensity-scale sensitometer of present design, on the other hand, uses no step tablet in contact with the test film strip and thus excludes dust. Also, as an additional advantage, error due to instability of the density of the steps in the step tablet is eliminated. Pure intensity scale is obtained without the intervention of any absorbing medium.

PART 1

GENERAL DESIGN

INTRODUCTION

This part will discuss the guidelines for the design of the sensitometer in accordance with the requirements set forth for the sensitometer. The design of the intensity-scale sensitometer can be broadly divided into the design of four major components:

1. Light source & Reflector
2. Diaphragm
3. Lens & Cojugate distances
4. Test film strip holder

The various components are however interdependent, and in the general design, it is necessary to consider them together. The factors that affect only the individual component under consideration can be dealt with separately. For convenience, the design is dealt with under the major heads mentioned above, though they may overlap one another.

LIGHT SOURCE AND REFLECTOR

Two sets of lamps were used as light sources. One set consisted of Tungsten Iodide lamps and the other set Pulsed Xenon arc lamps. In either case, the illumination falling on the reflector was to be made as uniform as possible by use of a reflector and suitable orientation of the lamps with respect to the reflector.

The reason for using the General Electric Quartzline lamps was the relatively stable light output over the life-time of the lamps. The pulsed Xenon arc lamps (PXA) have been specially developed for the Graphic arts industry and offer the advantage of stable light output, instant start and daylight quality color temperature. The wavelength of light emitted ranges from 400 to 800 nanometers.

Illumination of the Reflector by the lamps

For the purpose of calculating the illumination falling on the surface of the reflector, the lamps will be assumed to be uniform point sources of light.

In Fig.2 below, let I be the luminous intensity of each lamps L1 and L2, assumed equal, in a direction normal to the surface of the reflector. Then the illumination E_d at point D on the reflector surface which lies in the plane containing the lamps L1 and L2 and the normal to the surface of the reflector will be given by:

$$E_d = I(\cos^3 \phi_1 + \cos^3 \phi_2)/b^2$$

$$\cos \phi_1 = b/\left[b^2 + (a + c)^2\right]^{\frac{1}{2}}$$

$$\cos \phi_2 = b/\left[b^2 + (a - c)^2\right]^{\frac{1}{2}}$$

$$E_d = \frac{I}{b^2} \quad \frac{b^3}{\left[b^2 + (a + c)^2\right]^{3/2}} + \frac{b^3}{\left[b^2 + (a - c)^2\right]^{3/2}}$$

$$E_d = \frac{I}{b^2} \quad \frac{1}{\left[1 + \left(\frac{a}{b} + \frac{c}{b}\right)^2\right]^{3/2}} + \frac{1}{\left[1 + \left(\frac{a}{b} - \frac{c}{b}\right)^2\right]^{3/2}}$$

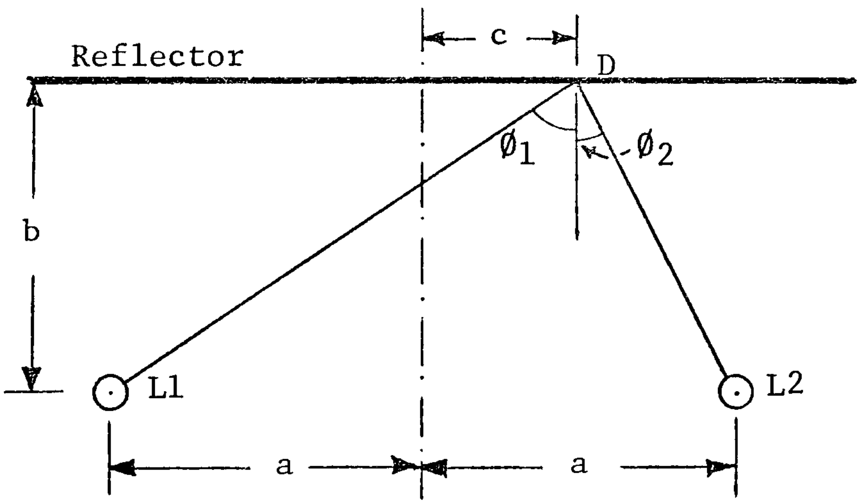


Fig.2 Illumination of reflector - horizontal plane

For a given luminous intensity I of lamps, the illumination E_d will depend on the distances a, b and c as given by the above equation.

Expressing a and c as fractions of b, the illumination at various points on the surface of the reflector in the same plane as point D can be calculated. Table 1, pages 12 and 13 shows the illumination values so obtained.

Plotting $(E_d b^2/I)$ against (c/b) for different values of (a/b) (0.4, 0.5, 0.6), we get a series of curves as shown in Fig. 4, page 14. These curves show how the illumination varies along a line lying in the plane containing the lamps and the normal to the surface.

Following a similar procedure for calculating the illumination along a vertical line on the reflector surface due to two lamps placed one above the other, the same result as for the illumination of the horizontal line and horizontal orientation of the two lamps will be obtained. Fig. 3, page 15, shows lamp L3 situated vertically above lamp L1 and separated from it by a distance 2a. By symmetry, the curves in Fig. 4, page 14, for the horizontal orientation will also be valid for the vertical orientation of the lamps.

$\frac{a}{b}$	$\frac{c}{b}$	$\left[1+\left(\frac{a}{b}+\frac{c}{b}\right)^2\right]^{-3/2}$	$\left[1+\left(\frac{a}{b}-\frac{c}{b}\right)^2\right]^{-3/2}$	$\frac{E_d b^2}{I}$
0.1	0.0	0.9852	0.9852	1.9704
0.1	0.1	0.9429	1.0000	1.9429
0.1	0.3	0.8004	0.9429	1.7433
0.1	0.5	0.6305	0.8004	1.4309
0.1	0.7	0.4761	0.6305	1.1066
0.1	0.9	0.3536	0.4761	0.8297
0.2	0.0	0.9429	0.9429	1.8858
0.2	0.1	0.8787	0.9852	1.8639
0.2	0.3	0.7155	0.9852	1.7007
0.2	0.5	0.5498	0.8787	1.4285
0.2	0.7	0.4107	0.7155	1.1262
0.2	0.9	0.3044	0.5498	0.8542
0.3	0.0	0.8787	0.8787	1.7575
0.3	0.1	0.8004	0.9429	1.7433
0.3	0.3	0.6305	1.0000	1.6305
0.3	0.5	0.4761	0.9429	1.4190
0.3	0.7	0.3536	0.8004	1.1540
0.3	0.9	0.2624	0.6305	0.8929
0.4	0.0	0.8004	0.8004	1.6008
0.4	0.1	0.7155	0.8787	1.5942
0.4	0.3	0.5498	0.9852	1.5350
0.4	0.5	0.4107	0.9852	1.3959
0.4	0.7	0.3044	0.8787	1.1831
0.4	0.9	0.2267	0.7155	0.9422
0.5	0.0	0.7155	0.7155	1.4311
0.5	0.1	0.6305	0.8004	1.4309
0.5	0.3	0.4761	0.9429	1.4190
0.5	0.5	0.3536	1.0000	1.3536
0.5	0.7	0.2624	0.9429	1.2053
0.5	0.9	0.1964	0.8004	0.9968

(continued on page 13)

Table 1: Illumination due to two lamps

$\frac{a}{b}$	$\frac{c}{b}$	$\left[1+\left(\frac{a}{b}+\frac{c}{b}\right)^2\right]^{-3/2}$	$\left[1+\left(\frac{a}{b}-\frac{c}{b}\right)^2\right]^{-3/2}$	$\frac{E_d b^2}{I}$
0.6	0.0	0.6305	0.6305	1.2610
0.6	0.1	0.5498	0.7155	1.2653
0.6	0.3	0.4107	0.8787	1.2894
0.6	0.5	0.3044	0.9852	1.2896
0.6	0.7	0.2267	0.9852	1.2119
0.6	0.9	0.1707	0.8787	1.0494
0.7	0.0	0.5498	0.5498	1.0996
0.7	0.1	0.4761	0.6305	1.1066
0.7	0.3	0.3536	0.8004	1.1540
0.7	0.5	0.2624	0.9429	1.2053
0.7	0.7	0.1964	1.0000	1.1964
0.7	0.9	0.1489	0.9429	1.0918
0.8	0.0	0.4761	0.4761	0.9522
0.8	0.1	0.4107	0.5498	0.9605
0.8	0.3	0.3044	0.7155	1.0199
0.8	0.5	0.2267	0.8787	1.1054
0.8	0.7	0.1707	0.9852	1.1559
0.8	0.9	0.1303	0.9852	1.1155
0.9	0.0	0.4107	0.4107	0.8213
0.9	0.1	0.3536	0.4761	0.8297
0.9	0.3	0.2624	0.6305	0.8929
0.9	0.5	0.1964	0.8004	0.9968
0.9	0.7	0.1489	0.9429	1.0918
0.9	0.9	0.1145	1.0000	1.1145
1.0	0.0	0.3536	0.3536	0.7071
1.0	0.1	0.3044	0.4107	0.7151
1.0	0.3	0.2267	0.5498	0.7765
1.0	0.5	0.1707	0.7155	0.8862
1.0	0.7	0.1303	0.8787	1.0090
1.0	0.9	0.1010	0.9852	1.0862

(continued from page 12)

Table 1: Illumination due to two lamps

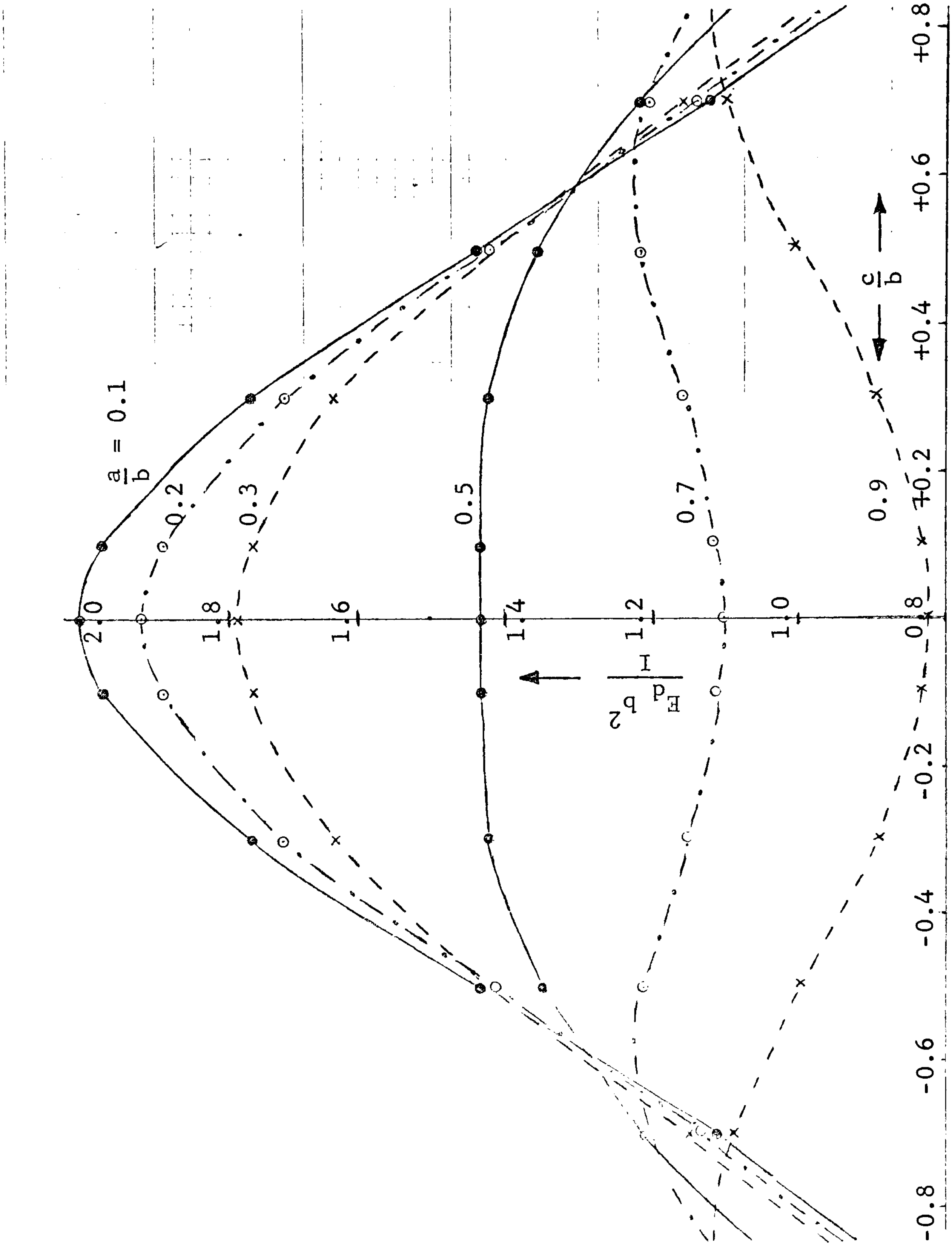


Fig.4 Illumination distribution on reflector

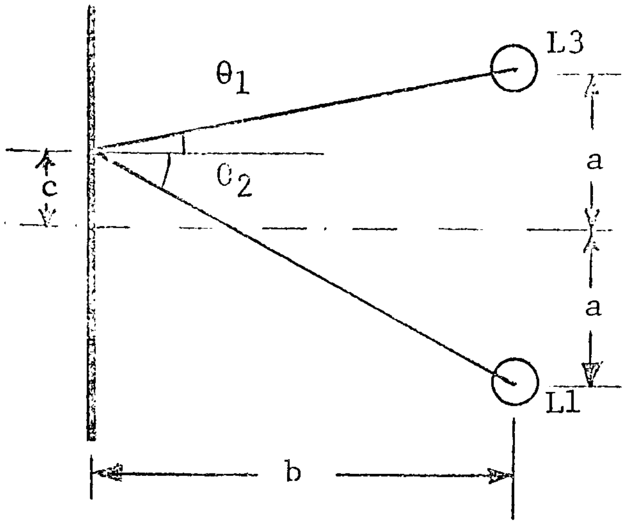


Fig.3 Illumination of reflector - vertical plane

From the illumination curves for the two lamps in Fig.4, page 14, it is seen that a value of 0.3 for the ratio (a/b) produces a peak illumination at the center with a steep fall in the illumination as the distance from the center increases. A value of 0.7 for the ratio (a/b), on the other hand, produces a two-peaked curve (the peaks approximately corresponding to the projection of the lamps on the reflector surface), with illumination falling off on either side of the two peaks. A value of 0.5 for the ratio (a/b) produces a curve which is fairly flat in the center region with gradual decrease in the illumination as the distance from the center increases. For this reason, the value for (a/b) was chosen to be 0.5, or, the distance b between the lamps and the reflector board was made equal to the distance 2a between the lamps in the horizontal as well as vertical directions. Fig.5, page 17, shows the orientation of the four lamps and the reflector board incorporating this result.

The illumination of the reflector by the combined effect of the four lamps can now be calculated. The illumination over an area of 2b x 2b will be calculated where b is the distance between the lamps and the reflector board. The distance 2a between the lamps in the vertical as well as horizontal direction is b as already decided.

The illumination at a point P (x,y) on a co-ordinate system with center of the reflector as the origin will be determined. The illumination at this point P due to lamp L1 only will first be calculated and the result extended to the other three lamps.

The illumination E_{p1} at point P due to lamp L1 only is given by: $E_{p1} = I \cos^3 \phi / b^2$, where ϕ is the angle between the line connecting lamp L1 and point P and the normal from lamp L1 to the reflector surface. Cos ϕ, therefore is the ratio equal to (distance from lamp to reflector/distance from lamp to point P).

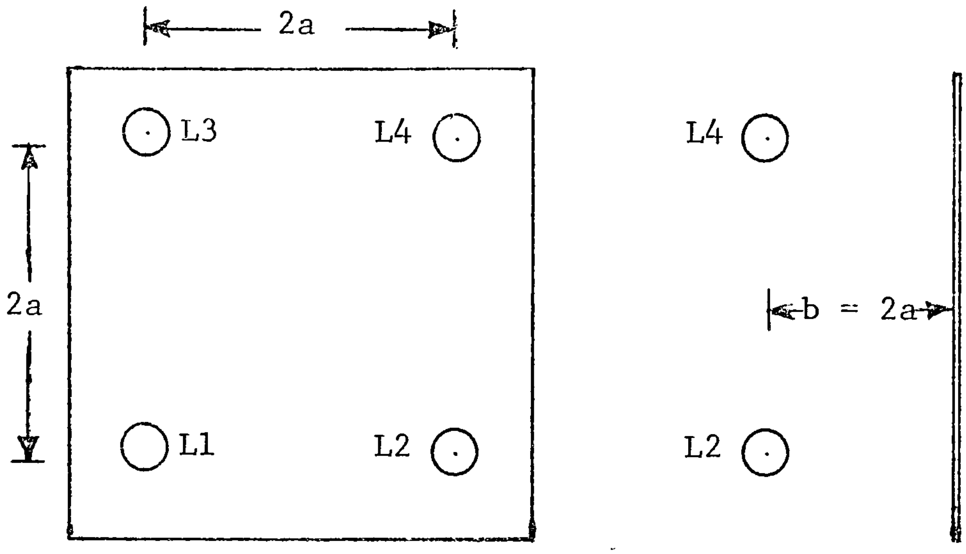


Fig. 5 Lamp and Reflector distances

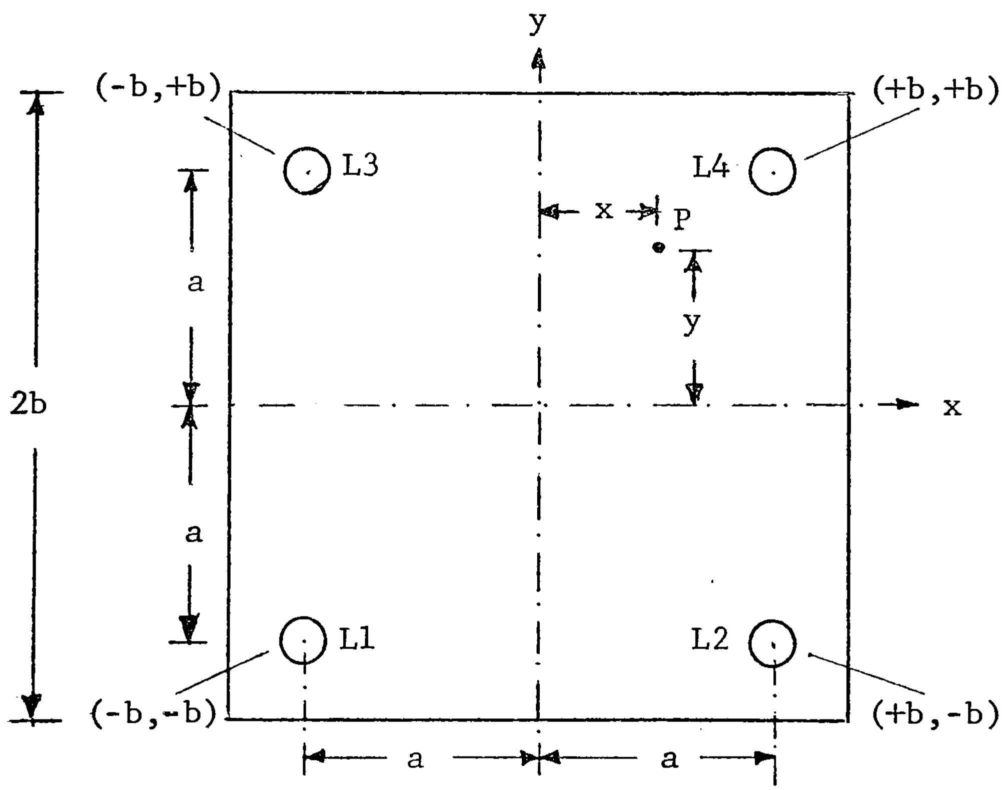


Fig.6 Illumination on Reflector

The distance from lamp to reflector is b, and the distance from lamp to point P can be calculated as shown below. The distance between the projection of the lamp L1 and point P is: $\sqrt{(x+a)^2 + (y+a)^2}$. As the lamp L1 is distant b from the reflector, the distance between the lamp L1 and point P is: $\sqrt{(x+a)^2 + (y+a)^2 + b^2}$. Therefore, $\cos \phi = b/\sqrt{(x+a)^2 + (y+a)^2 + b^2}$.

$$E_{p1} = \frac{I}{b^2} \frac{b^3}{\left[(x+a)^2 + (y+a)^2 + b^2\right]^{3/2}}$$

$$= \frac{I}{b^2} \frac{1}{\left[\left(\frac{x+a}{b}\right)^2 + \left(\frac{y+a}{b}\right)^2 + 1\right]^{3/2}}$$

$$= \frac{I}{b^2} \frac{1}{\left[\left(0.5 + \frac{x}{b}\right)^2 + \left(0.5 + \frac{y}{b}\right)^2 + 1\right]^{3/2}}$$

This is the illumination at point P due to lamp L1 only. The term that will be different for the lamps L2, L3 and L4 is $\cos \phi$, as this involves the distance between the point P and the lamp under consideration, which will be different for each lamp. From Fig.6, page 17, the $\cos \phi$ term for each lamp can be found:

$\cos \phi$ for lamp L2: $b/\sqrt{(x-a)^2 + (y+a)^2 + b^2}$

$\cos \phi$ for lamp L3: $b/\sqrt{(x+a)^2 + (y-a)^2 + b^2}$

$\cos \phi$ for lamp L4: $b/\sqrt{(x-a)^2 + (y-a)^2 + b^2}$

The total illumination E_p at point P due to all the four lamps is then given by:

$$E = \frac{I}{b^2} \frac{1}{\left[\left(0.5 + \frac{x}{b}\right)^2 + \left(0.5 + \frac{y}{b}\right)^2 + 1\right]^{3/2}} +$$

$$\frac{I}{b^2} \frac{1}{\left[\left(0.5 - \frac{x}{b}\right)^2 + \left(0.5 + \frac{y}{b}\right)^2 + 1\right]^{3/2}} +$$

$$\frac{I}{b^2} \frac{1}{\left[\left(0.5 + \frac{x}{b}\right)^2 + \left(0.5 - \frac{y}{b}\right)^2 + 1\right]^{3/2}} +$$

$$\frac{I}{b^2} \frac{1}{\left[\left(0.5 - \frac{x}{b}\right)^2 + \left(0.5 - \frac{y}{b}\right)^2 + 1\right]^{3/2}} .$$

Assigning different values to x and y, the illumination at points all over the reflector surface due to the four lamps can be calculated. For simplicity, the x and y values are expressed in terms of b, the distance between the lamps and the reflector. The illumination at various points on the surface of the reflector due to each of the four lamps is calculated and the total illumination computed in Table 2, page 20, using the formulae above.

To provide a better presentation of the illumination values at various points on the surface of the reflector, Table 3, page 21 is drawn up. This table shows the surface

$\frac{x}{b}$	$\frac{y}{b}$	Illumination due to Lamp*				Total Illumination*
		L1	L2	L3	L4	
0.0	0.0	0.5443	0.5443	0.5443	0.5443	2.1772
0.0	0.1	0.4895	0.4895	0.5973	0.5973	2.1736
0.0	0.2	0.4357	0.4357	0.6447	0.6447	2.1608
0.0	0.3	0.3849	0.3849	0.6825	0.6825	2.1348
0.0	0.4	0.3382	0.3382	0.7071	0.7071	2.0906
0.0	0.5	0.2963	0.2963	0.7156	0.7156	2.0238
0.1	0.0	0.4895	0.4895	0.5973	0.5973	2.1736
0.1	0.1	0.4433	0.5336	0.5336	0.6594	2.1699
0.1	0.2	0.3974	0.4718	0.5727	0.7156	2.1575
0.1	0.3	0.3536	0.4141	0.6037	0.7607	2.1321
0.1	0.4	0.3128	0.3617	0.6236	0.7902	2.0883
0.1	0.5	0.2758	0.3150	0.6305	0.8004	2.0217
0.2	0.0	0.4357	0.6447	0.4357	0.6447	2.1608
0.2	0.1	0.3974	0.5727	0.4718	0.7156	2.1575
0.2	0.2	0.3589	0.5035	0.5035	0.7802	2.1461
0.2	0.3	0.3217	0.4395	0.5284	0.8325	2.1221
0.2	0.4	0.2867	0.3818	0.5443	0.8669	2.0797
0.2	0.5	0.2545	0.3310	0.5498	0.8788	2.0141
0.3	0.0	0.3849	0.6825	0.3849	0.6825	2.1348
0.3	0.1	0.3536	0.6037	0.4141	0.7607	2.1321
0.3	0.2	0.3217	0.5284	0.4395	0.8325	2.1221
0.3	0.3	0.2905	0.4592	0.4592	0.8910	2.0999
0.3	0.4	0.2608	0.3974	0.4718	0.9295	2.0595
0.3	0.5	0.2331	0.3432	0.4761	0.9429	1.9953
0.4	0.0	0.3382	0.7071	0.3382	0.7071	2.0906
0.4	0.1	0.3128	0.6236	0.3617	0.7902	2.0883
0.4	0.2	0.2867	0.5443	0.3818	0.8669	2.0797
0.4	0.3	0.2608	0.4718	0.3974	0.9295	2.0595
0.4	0.4	0.2358	0.4073	0.4073	0.9708	2.0212
0.4	0.5	0.2123	0.3509	0.4107	0.9852	1.9591
0.5	0.0	0.2963	0.7156	0.2963	0.7156	2.0238
0.5	0.1	0.2758	0.8004	0.3150	0.6305	2.0217
0.5	0.2	0.2545	0.8788	0.3310	0.5498	2.0141
0.5	0.3	0.2331	0.9429	0.3432	0.4761	1.9953
0.5	0.4	0.2123	0.9852	0.3509	0.4107	1.9591
0.5	0.5	0.1925	1.0000	0.3536	0.3536	1.8997

* Actual illumination = Values in table x K (I/b^2)

Table 2: Illumination due to four lamps

+.5b	1.8997	1.9591	1.9953	2.0141	2.0217	2.0238	2.0217	2.0141	1.9953	1.9591	1.8997
+.4b	1.9591	2.0212	2.0595	2.0797	2.0883	2.0906	2.0883	2.0797	2.0595	2.0212	1.9591
+.3b	1.9953	2.0595	2.0999	2.1221	2.1321	2.1348	2.1321	2.1221	2.0999	2.0595	1.9953
+.2b	2.0141	2.0797	2.1221	2.1461	2.1575	2.1608	2.1575	2.1461	2.1221	2.0797	2.0141
+.1b	2.0217	2.0883	2.1321	2.1575	2.1699	2.1736	2.1699	2.1575	2.1321	2.0883	2.0217
0	2.0238	2.0906	2.1348	2.1608	2.1736	2.1772	2.1736	2.1608	2.1348	2.0906	2.0238
-.1b	2.0217	2.0883	2.1321	2.1575	2.1699	2.1736	2.1699	2.1575	2.1321	2.0883	2.0217
-.2b	2.0141	2.0797	2.1221	2.1461	2.1575	2.1608	2.1575	2.1461	2.1221	2.0797	2.0141
-.3b	1.9953	2.0595	2.0999	2.1221	2.1321	2.1348	2.1321	2.1221	2.0999	2.0595	1.9953
-.4b	1.9591	2.0212	2.0595	2.0797	2.0883	2.0906	2.0883	2.0797	2.0595	2.0212	1.9591
-.5b	1.8997	1.9591	1.9953	2.0141	2.0217	2.0238	2.0217	2.0141	1.9953	1.9591	1.8997
x --	-.5b	-.4b	-.3b	-.2b	-.1b	0	+.1b	+.2b	+.3b	+.4b	+.5b

Table 3: Illumination of Reflector

of the reflector divided into a number of segments and the value in each segment is the illumination in that segment and is obtained from Table 2, page 20. It can be seen from Table 3, page 21, that the illumination is maximum at the center of the reflector surface - coordinate (0,0) -, and decreases as the distance from the center increases. To find out how the illumination falls off as the distance from the center is increased, we can consider a circular area with OQ as the radius where O is the center (0,0) and Q a point away from the center. The illumination value in the segment containing the point Q as well as the illumination at the center can be read off Table 3, page 21. The average illumination and the maximum possible variation in illumination in the area under consideration can then be calculated. These data for points (0.1b,0.1b), (0.2b,0.2b) and (0.3b,0.3b) are calculated as shown below:

<u>Circular area of dia. 0.28b:(2 x 0.1b)/sin 45°</u>

$E_{center} = 2.1772K$

$E_{(0.1b,0.1b)} = 2.1699K$

$E_{average} = 2.1736K$

$$\text{Max. variation} = \frac{0.0036 \times 100}{2.1736} = 0.1656\ \%$$

<u>Circular area of dia. 0.56b: (2 x 0.2b)/sin 45°</u>

E_{center} = 2.1772K

$E_{(0.2b,0.2b)}$ = 2.1461K

$E_{average}$ = 2.1617K

Max. variation = $\frac{0.0156 \times 100}{2.1617}$ = 0.717%

<u>Circular area of dia. 0.84b: (2 x 0.3b)/sin 45°</u>

E_{center} = 2.1772K

$E_{(0.3b,0.3b)}$ = 2.0999K

$E_{average}$ = 2.1386K

Max. variation = $\frac{0.0386 \times 100}{2.1386}$ = 1.805 %

The calculation above shows that the smaller the diameter of the area considered, the lower the variation in the illumination in the area. To summarize the results:

Dia. of the area	0.28b	0.56b	0.84b
Max. variation	± 0.17 %	± 0.72 %	± 1.8 %

To achieve minimum variation in illumination, the area that is to be used should be as small as possible. Or, b should be small.

As b is increased, the illumination on the reflector surface decreases which is undesirable. Therefore, to obtain good illumination and minimum variation of illumination on the reflector, b should be kept at a low value. b is also the distance between the lamps themselves, and the physical dimensions of the lamps required b to be a certain minimum value. This minimum value was chosen for b, and the rest of the instrument designed so that the illuminated area used by the system was kept as small as possible to get minimum variation in the illumination. This discussion is dealt with in more detail in the section Lens and Conjugate distances, page 30.

DESIGN OF DIAPHRAGM

Illumination Range

The Log E range for films in Graphic arts industry given in Kodak Graphic arts data book varies from 1 to 4. In the present project, the Log E range was restricted to a value of 2.0. The Log E range of 2 for the illumination in the image plane would adequately cover the working range of most graphic arts film. For the stepped diaphragm, the range would be in a series of twenty-one steps, the illumination in the image plane corresponding to the 21st step and 1st step being such that the logarithm of their ratio is 2.

The values of minimum and maximum exposure times and maximum illumination figure were obtained from the Graphic Arts Research Center of Rochester Institute of Technology, Rochester, New York. Exposure times: 2 to 40 seconds. Illumination: Maximum 2000 lux.

Dimension of the Diaphragm steps

The total height of the diaphragm opening h is related to the length of the exposed portion of the test film strip h' by the expression: h = (s x h')/s', where s and s' are the object and image distances. The exposed portion of the test film strip h' was chosen to be 210 mm, and the focal length f of the cylindrical lens is 240 mm. The total diaphragm height h can then be calculated for various field angles. Fig. 7 below shows the object, the lens and the image formed by the lens. The relations are: h = (s x h')/s'; s' = h'/tan Ø; s = s'f/(s' - f).

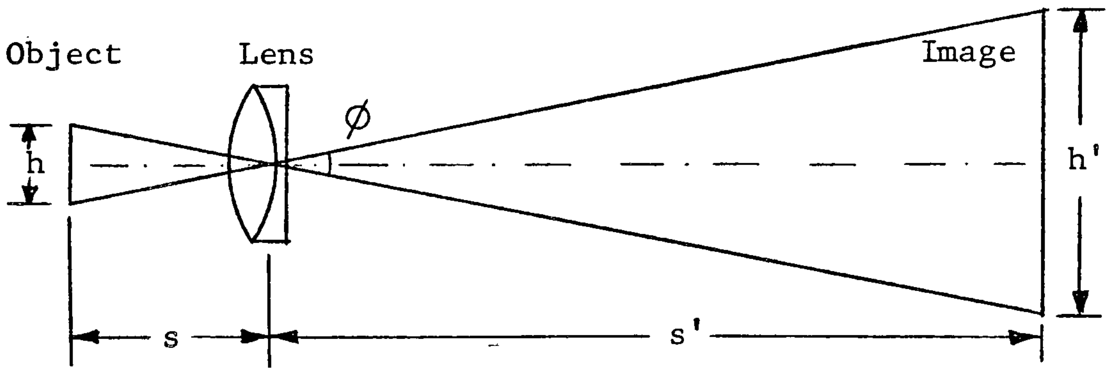


Fig.7 Diaphragm height

For Ø = 5°: s' = h'/tan Ø = 210/tan 5° = 2400 mm

s = s'f/(s'- f) = (2400 x 240)/2160 = 267 mm

h = (s x h')/s' = (268 x 210)/2400 = 23.4 mm

For $\emptyset = 10°$: $s' = h'/\tan \emptyset = 210/\tan 10° = 1191$ mm

$s = s'f/(s'-f) = (1191 \times 240)/951 = 301$ mm

$h = (s \times h')/s' = (301 \times 210)/1191 = 53$ mm

The number of steps to be produced in the film strip was chosen to be 21. Then, the height of each step in the diaphragm becomes 1.11 mm (23.4/21) for $\emptyset = 5°$, and 2.5 mm (53/21) for $\emptyset = 10°$. The height of each step in either case is thus very small, and it is not possible to achieve these dimensions with accuracy if the steps were to be manually made in the diaphragm.

It is seen that the larger field angle allows the dimensions of the steps to be large enabling them to be made with more accuracy. On the other hand, the larger field angle will introduce larger nonuniformity of illumination in the image. Therefore, there has to be a compromise between the field angle and the dimensions of the step in the diaphragm. The conjugate distances which decide both the field angle and the dimensions of the step in the diaphragm were thus dependent on the method by which the steps in the diaphragm were to be made.

The Log E range at the image plane was chosen to be 2.

Then, Log $(E_{21}/E_1) = 2$. Or, $(E_{21}/E_1) = 100$. The width w_{21} and w_1 of the 21st and 1st steps in the diaphragm will then have the relationship, $(w_{21}/w_1) = (E_{21}/E_1) = 100$. The ratio of the adjacent steps will be given by the relationship, Log $(w_{x-1}/w_x) = (2/20) = 0.1$. Once the width of the first step or the last step is chosen, the width of all other steps can be calculated using this relationship.

Diaphragm for Continuous modulation

A second diaphragm whose opening varied continuously instead of in a stepped manner was to be made for generating continuous gradation in the illumination falling on the test film strip at the image plane. The contour of the opening was such that the logarithm of illumination of light falling on the image plane would vary linearly and continuously from one end to the other. This diaphragm will be useful in plotting a continuous D-Log E curve of the test film strip by scanning it in an automatic recording type densitometer.

Method of making diaphragm steps

A large drawing of the contour of the steps of the diaphragm was proposed to be made on a drawing paper and by photographing this on a photographic material, a diminutive image of exact dimensions required by the design could be made. The photographic material after processing could then function as the diaphragm with the stepped or continuous contour.

There were several factors involved in this method of producing the diaphragm steps: (i) The type of photographic material to be used (ii) The maximum density that could be obtained with the photographic material. This had to be sufficiently high so that this portion of the photographic material acted as a highly opaque plate (iii) The fog produced in the photographic material. This had to be sufficiently low so that portions of the material having fog were highly transparent (iv) Modification of the light qualitatively or quantitatively by the fogged portions of the photographic material (v) The sharpness of the image produced in the photographic material (vi) The uniformity of density in the dark and light portions of the photographic image.

The selection of the photographic material to be used as the diaphragm depended on how well the material met the requirements mentioned above. This topic is covered in more detail in Part III, Construction of Sensitometer, page 60.

LENS & CONJUGATE DISTANCES

The object distance s and the image distance s' were chosen so that the illumination falling on each band of the image was fairly uniform throughout the band and the instrument was as compact as possible.

From the calculations in pages 22 and 23, it is clear that smaller the area of the reflector used the better the uniformity of illumination will be on the reflector surface. This would call for a large object distance s and consequently a large image distance s', as the image distance is greater than the object distance. The apparatus as a result would be large, and because of the large size, the illumination at the image plane would be low. Under the circumstances, there had to be a compromise between the uniformity of illumination of the reflector surface and the compactness of the apparatus or the level of illumination at the image plane. On the other hand, it was desirable to keep the apparatus reasonably large to insure small field angles so that the first order equations would be valid.

The width of steps formed in the image plane was taken to be 10 mm. As the height of step in the diaphragm was 2.5 mm, this gave the relation $s'/s = h'/h = 10/2.5 = 4$. $s' = 4s$, and $(1/s) + (1/s') = (1/f)$. Therefore $s = 300$ mm and $s' = 1200$ mm, since $f = 240$ mm. This gave a field angle $\emptyset = \tan^{-1}(h'/s') = 0.48°$ which was not unduly great. The arrangement of the diaphragm, lens and film would then be as shown in Fig.8 below.

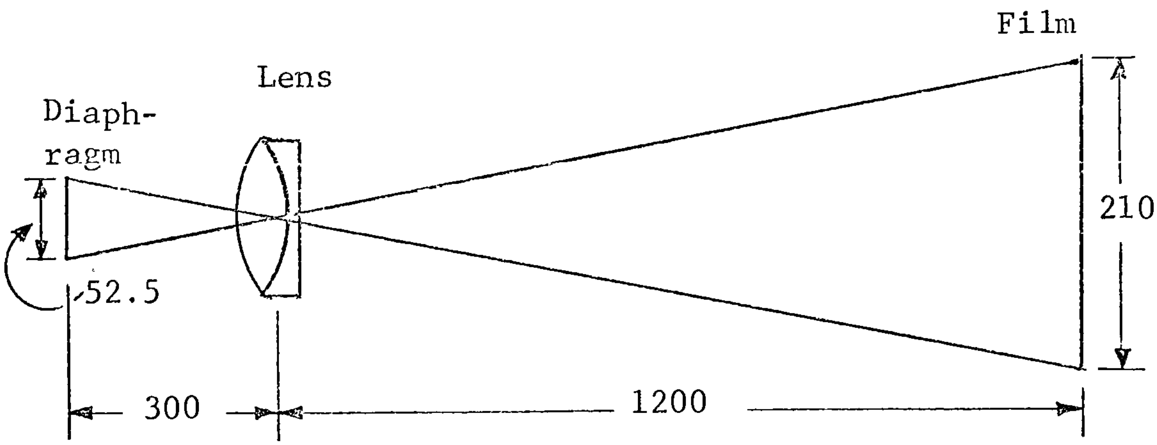


Fig.8 Conjugate distances

TEST FILM-STRIP HOLDER

In the design of the film holder, the method of inserting and removing the test film strip and holding the film strip flat during exposure should be considered. To keep the film flat against the film holder, a vacuum back was proposed to be used. The film holder is the part of instrument the operator will use to expose the test film strip and it should therefore be easily accessible. The design of the film holder should also permit easy insertion and removal of the test film strip.

The width of the strip to be used in the instrument was chosen to be 16 or 35 mm so that film strips of either standard commercial size could be tested in the instrument.

The number of steps in the image formed on the test film strip was already chosen to be 21, and the width of each density step was chosen to be 10 mm.

PART 2

CALCULATION OF PHYSICAL DIMENSIONS

GENERAL

This part will deal with the calculation of physical dimensions of the various components to meet the design requirements.

Distance between lamps, conjugate distances and distance between diaphragm and reflector will be finalyzed. The width and height of steps in the diaphragm will be chosen.

DISTANCE BETWEEN LAMPS

In order to make the apparatus as compact as possible, the distance 2a between the lamps, Fig.5, page 17, must be small. The physical dimensions of the PXA 43 lamps and the Tungsten Iodide lamps required the distance 2a to be at least 317.5 mm. Choosing this minimum distance, distance between the lamps 2a was fixed at 317.5 mm.

It was shown on page 15 that the distance 2a between the lamps and the distance b between the lamp board and the reflector should be same to have fairly uniform illumination on the surface of the reflector. Therefore, the distance b was chosen to be 317.5 mm.

DIAPHRAGM

At the film plane, the Log E range was chosen to be 2. The number of steps in the diaphragm was 21. The ratio of width of the 21st step to that of the 1st step was then 100. The width of the first step w_1 was chosen to be 0.5 mm. The width of the 21st step then would be 50 mm. Selecting the height of the diaphragm to be approximately the same as the width of its largest step, the dimensions of the diaphragm became:

Width: First step = 0.5 mm; Last step = 50 mm

Height: Each step = 2.5 mm; Total = 52.5 mm

Using the relation, Log $(w_{x-1}/w_x) = 0.1$, the width of all intermediate steps were calculated and Table 4, page 37, shows the values.

Step x	Width w_x in mm	Step x	Width w_x in mm
1	0.5000	12	6.2946
2	0.6295	13	7.9245
3	0.7924	14	9.9763
4	0.9976	15	12.5594
5	1.2559	16	15.8113
6	1.5811	17	19.9053
7	1.9905	18	25.0593
8	2.5059	19	31.5479
9	3.1548	20	39.7164
10	3.9716	21	50.0000
11	5.0000		

Table 4 Width of diaphragm steps

CONJUGATE DISTANCES

The height of each step of the diaphragm will be imaged by the cylindrical lens as the width of the density steps formed on the test film in the image plane. The width of the density steps in the test film was chosen to be 10 mm. Height of each step in the diaphragm was also chosen to be 2.5 mm. The magnification of the optical system is therefore 4. The focal length of the cylindrical lens is 240 mm. From these data, the conjugate distances can be calculated and are as shown in Fig.8, page 31.

DIAPHRAGM TO REFLECTOR DISTANCE

Selecting a variation of not more than $\pm$ 0.72% in the illumination on the reflector surface, it could be seen from page 23 that a uniformly illuminated circle of diameter 0.56b or 177.8 mm would be the maximum reflected area viewed by the lens thru the diaphragm. The cylindrical lens is 80 mm wide and 55 mm high. Allowing a total of 5 mm on the width and height for the space to be taken up by the holder on which the lens would be mounted, the maximum clear area of the lens was 75 mm x 50 mm. The maximum clear area of the diaphragm was 50 mm x 52.5 mm. The distance between the lens and the diaphragm was 360 mm. The largest of the dimensions in the clear area of the lens and the diaphragm was considered to calculate the distance y between the reflector and the diaphragm. In Fig.9, page 40, $\frac{x}{52.5} = \frac{300 - x}{75}$. x was therefore 123.5 mm. $\frac{123.5 + y}{177.8} = \frac{123.5}{52.5}$, or y = 294.8 mm.

The reflector to diaphragm distance y was found to be 294.8 mm. The distance between the lamp board and the ref-

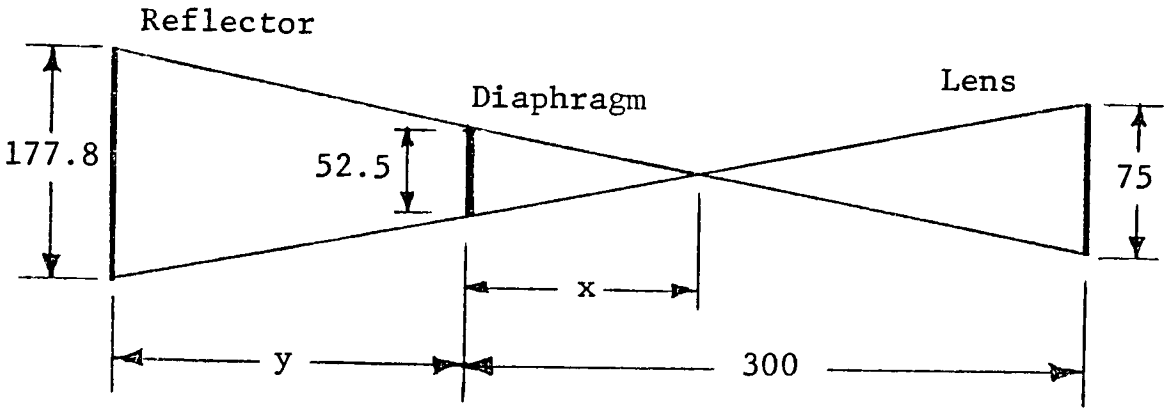


Fig.9 Reflector to diaphragm distance

lector was 317.5 mm, a necessity dictated by the physical dimensions of the lamps. This meant that the diaphragm would be located between the lamps and the reflector. There were two disadvantages to such a location: (i) the diaphragm housing would obstruct the light from the lamps to the reflector, and an attempt to avoid this shadow would increase the distance between the lamp board and reflector with consequent increase in the size of the instrument (ii) the cooling of the lamps by the fan would be less efficient because of the obstruction caused by the diaphragm housing. For these reasons and for simplifying the construction, it was decided to locate the diaphragm directly on the lamp board. Then the area of the reflector viewed by the lens thru the diaphragm, and the variation in illumination of the area viewed could be calculated. From Fig.10 below,

$$\frac{z}{317.5 + 123.5} = \frac{52.5}{123.5} . \quad \text{Or } z = 187.5 \text{ mm.}$$

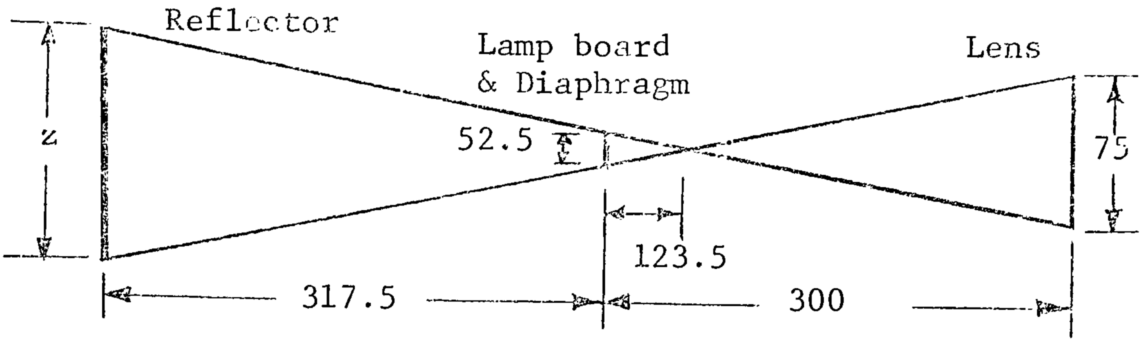


Fig.10 Location of diaphragm

The maximum area of the reflector as seen by the lens thru the diaphragm was now a circle of diameter z = 187.5 mm or 0.59b, b being the distance between the lamp board and the reflector. The expression on page 19 by which the illumination at any point on the reflector surface can be calculated, and the method employed on page 22 to calculate the variation in illumination over a selected area can be used to find out the maximum variation in illumination in a circle of diameter z = 0.59b. The coordinates for the segment would be 0.59 sin 45°/2, 0.59 sin 45°/2. The illumination values for the center, the segment under consideration and the average were calculated.

$$E_{center} = 2.1772K$$

$$E_{(0.21b,\ 0.21b)} = 2.1425K$$

$$E_{average} = 2.1599K$$

$$\text{Max. variation} = \frac{0.0174 \times 100}{2.1599} = 0.81\%$$

COMPONENT LAYOUT

From the foregoing sections, the distance between the various components making up the sensitometer were decided and are shown in Fig.11 below.

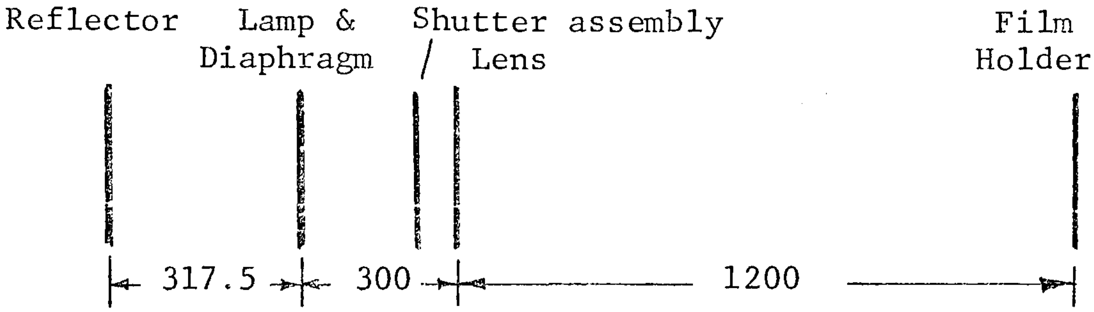


Fig.11 Component layout

The total length of the sensitometer was thus 1817.5 mm. One of the main requirements of the sensitometer was that it should be compact which indicated a vertical arrangement of the instrument. Secondly, the instrument was to fit in a room of normal height, 8 feet or 2.44 m. A third desirable feature in the sensitometer was that the film holder should be at a convenient height from the floor level so that the person operating the instrument would be able to insert and remove the test film strip without much difficulty. A height of 3 feet or 0.91 m from the floor would be a convenient height. These considerations meant that the total length of the sensitometer should be no more than 1.53 m (2.44 -.91). The total length of the instrument arrived at was 1.82 m, as shown in Fig.11, page 43. It was apparent that the instrument had to be redesigned to meet the requirements under consideration.

One solution was to bend the optical axis. The height of the room was 2438 mm (8 feet), and the height of the film plane above the floor was chosen to be 914 mm (3 feet). Allowing a 75 mm clearance between the top of the instrument and the ceiling, the maximum length for the vertical portion of the instrument was to be 1449 mm minus half the width of the horizontal portion of the instrument. The width of the instrument had to be at least as much as the distance between the two lamps, which was 317.5 mm plus clearance of 200 mm for wiring the lamps, or a total of 517.5 mm. The vertical portion of the instrument could not therefore be more than 1190 mm (1499 - 259). That is, the reflector, lamp board, diaphragm, shutter assembly and the lens would all have to be located in the horizontal portion of the instrument above the vertical portion which would contain only the film holder. Fig.12 below shows the arrangement of the components under this scheme.

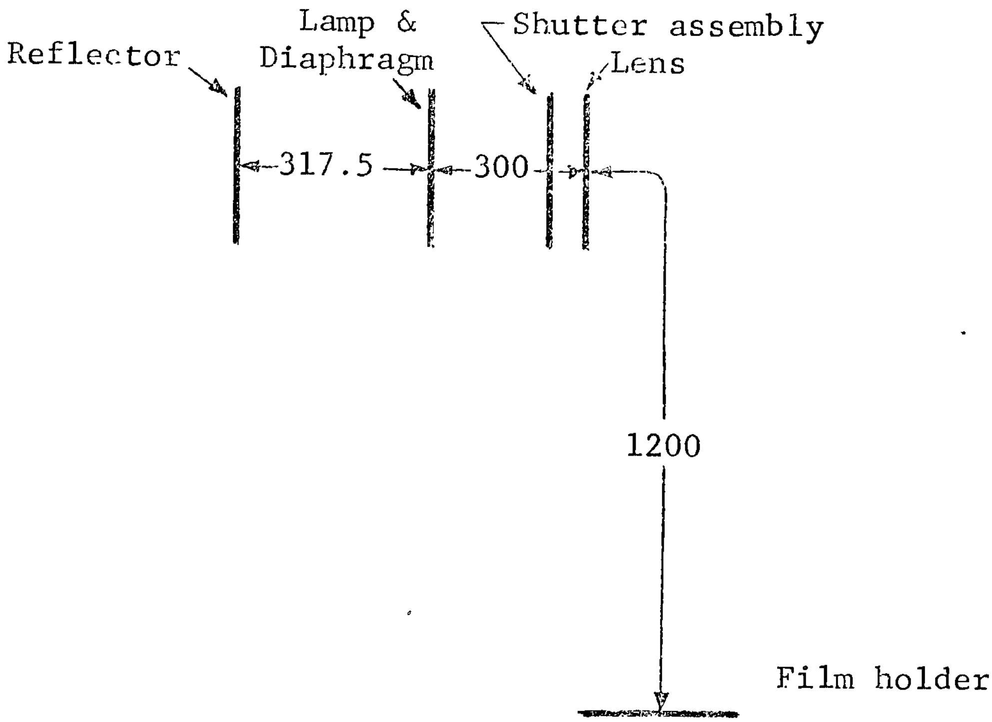


Fig.12 Component orientation

The heaviest component in the sensitometer is the shutter assembly. With the optical axis bent as shown in Fig.12 above to meet the design requirements, the shutter assembly would fall outside the base of the instrument causing instability. The second disadvantage with this scheme would be the necessity to have an extra component, the reflector to bend the optical axis. It would also be necessary to have some means of rotating the angle of the reflector about two mutually perpendicular axes to get the image aligned correctly in the film plane.

Because of the disadvantages of bending the optical axis, a second method was considered. The length of the apparatus consisted of the reflector to diaphragm distance and the diaphragm to film distance. The reflector to diaphragm distance, 317.5 mm could not be reduced as this was the minimum value possible to physically mount the lamps on the lamp board. But the diaphragm to film distance (s + s') was not so inflexible. The parameter that gave rise to the value of s = 300 mm and s' = 1200 mm was the magnification of the system. The magnification chosen was 4 to get 10 mm wide steps in the image obtained in the film plane. As the magnification approached unity, the total distance (s + s') approached a minimum value. But a unit magnification would yield 2.5 mm wide steps in the image formed on the test film strip. This value for the width would be too low. Therefore the magnification was given a revised value of 2. The object distance s and the image distance s' were then 360 and 720 mm respectively. This made the apparatus 1398 mm long, which was well below the maximum value of 1530 mm. The only drawback to this scheme would be the reduced width of density steps in the image formed on the test film. This was not a serious limitation as 5 mm width would be sufficient.

On the other hand, there were some advantages arising out of the revised value for the magnification. The field angle in the revised arrangement would be $\tan^{-1}(52.5/360)$ or 8.29° as opposed to the original field angle of $\tan^{-1}(52.5/300)$ or 9.93°, an improvement of 16%.

The value for the maximum variation in the illumination of the reflector area as viewed by the lens was calculated to be 0.81% for a magnification of 4 as developed in the section "Diaphragm to reflector distance", pages 39 thru 42. The new value for the maximum variation with a magnification of 2 could be calculated by redrawing Fig.9, page 40 with the new object distance and calculating other distances. Fig.13, page 48 shows the same arrangement as Fig.9, page 40, but with the new object distance of 360 mm instead of the original 300 mm. From Fig.13, page 48,

$\frac{x}{52.5} = \frac{360 - x}{75}$. Or x = 148.2 mm. As before, the

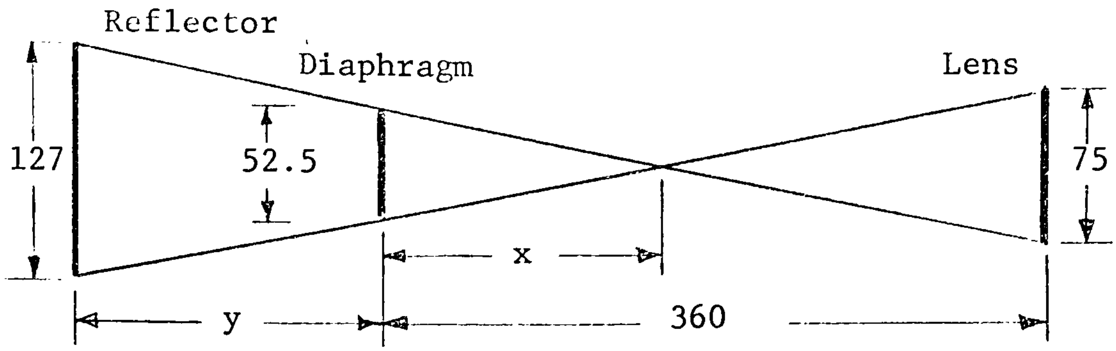


Fig.13 Reflector to diaphragm distance

diaphragm would be mounted directly on the lamp board. The distances shown in Fig.10, page 41 would then be changed as shown in Fig.14 below. From Fig.14, $\frac{z}{317.5 + 148.2} = \frac{52.5}{148.2}$. Or, z = 164.9 mm.

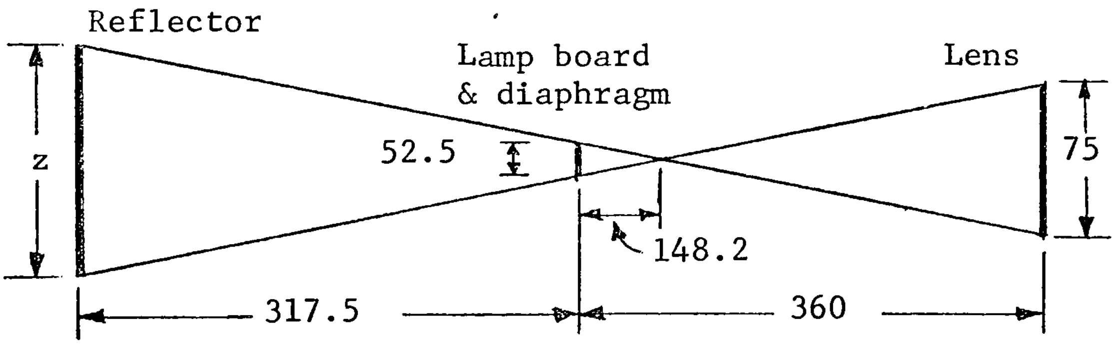


Fig.14 Location of diaphragm

The maximum area of the reflector as seen by the lens thru the diaphragm would then be a circle of diameter z = 164.9 mm or 0.52b. The expression on page 19 by which the illumination at any point on the reflector surface could be calculated, and the method employed on page 22 to calculate the variation in illumination over a selected area could once again be used to find out the maximum variation in illumination in a circle of diameter z = 0.52b. The coordinates for the segment would be 0.52b sin 45°/2, 0.52b sin 45°/2 or, 0.18b, 0.18b. The illumination values for the center, the segment under consideration and the average were calculated.

$$E_{center} = 2.1772K$$

$$E_{(0.18b,\ 0.18b)} = 2.1511K$$

$$E_{average} = 2.1641K$$

$$\text{Max. variation} = 0.0130 \times 100 = 0.6\%$$

The maximum variation in the illumination of the reflector surface as viewed by the lens thru the diaphragm was 0.81% with the original magnification of 4. Thus, there was an improvement of 26% with the revised magnification value of 2.

The component layout with the revised values of magnification and consequently the object and image distances are shown in Fig.15 on page 50.

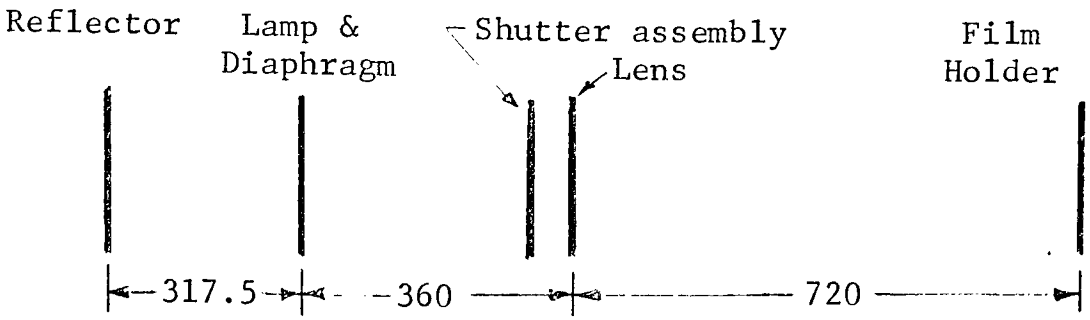


Fig.15 Component layout

PART 3

CONSTRUCTION OF SENSITOMETER

GENERAL

This part will describe the methods used to fabricate various parts of the apparatus according to the physical dimensions arrived at in previous sections and design criteria.

The major components dealt with are, lamp board, reflector, diaphragm, lens holder, test film holder and PXA lamp power supply chassis.

LAMP BOARD

The four PXA and four Tungsten iodide lamps were arranged on the lamp board as shown in Fig. 16, page 54. The area covered by the lamps was 449 mm x 449 mm or approximately 18 inch x 18 inch. Allowing 3 inches on all the four sides for laying out the cable and to secure a supporting framework, the lamp board was chosen to be a galvanized steel sheet 24 inch x 24 inch and 1/16 inch thick. Fig.17, page 55 shows the details of the lamp board and the mounting arrangement for the lamps.

The framework on which the lamp board was secured was made from 1½" x 1½" x 3/16" angle irons. The frame was secured to four 3/4" screw rods through the holes at the corners and held in position by nuts. The screw rod permitted the framework to be slid to any position and secured there by means of nuts. Fig.18, page 56 shows the details of the framework to which the lamp board was secured.

All major components such as reflector, shutter assembly, and the film holder were mounted in frameworks of the

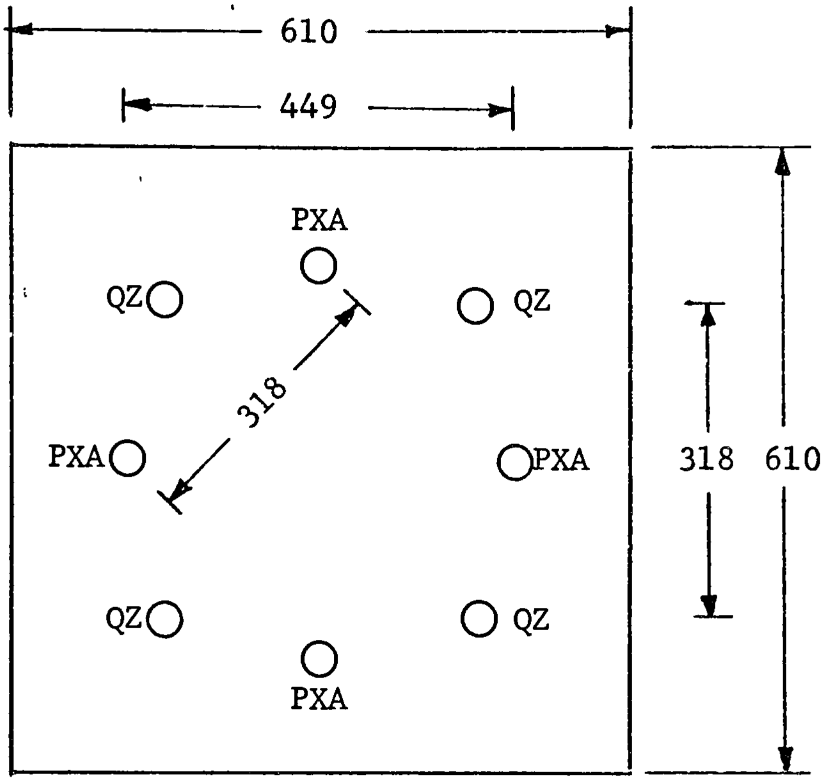
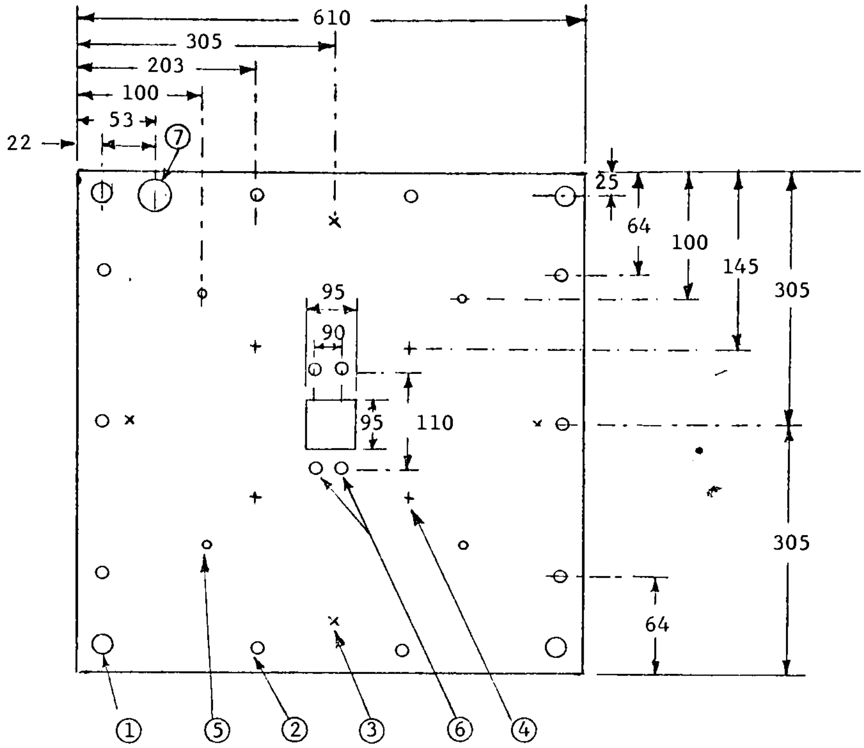


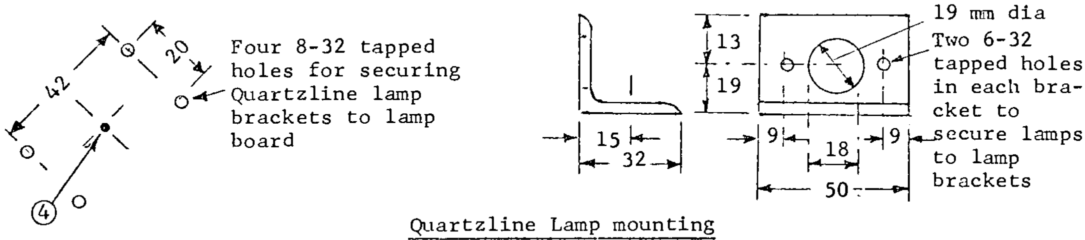
Fig.16 Position of lamps on the Lamp board

same size and secured the same way. This feature enabled easy adjustment of the distance between the components and alignment.

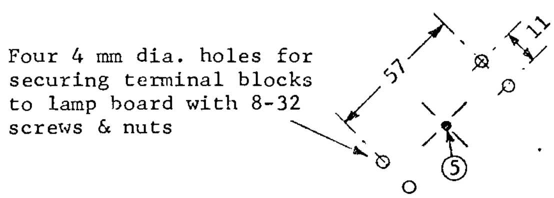
The advantage of mounting the diaphragm on the lamp board rather than separately was seen in the section Diaphragm to reflector distance, pages 39 thru 42. Accordingly, Fig. 17, page 55 shows the opening and mounting arrangement provided for the diaphragm in the lamp board.



① Four holes 21 mm dia. for inserting four 3/4" screw rods. ② Ten holes 4 mm dia. for securing lamp board to Lamp board frame (Fig.18, page 56) by 6-32 screws. ③ Centerline for mounting PXA lamp brackets. The two brackets for each lamp are secured by 8-32 screws and nuts passing through two 4 mm dia. holes spaced 40 mm from centerline. ④ Centerline for mounting Quartzline lamp brackets. ⑤ Centerline terminal blocks for wiring the lamps. ⑥ Mounting arrangement for diaphragm. ⑦ 22 mm dia. hole for inserting rubber grommet through which the wires are run.

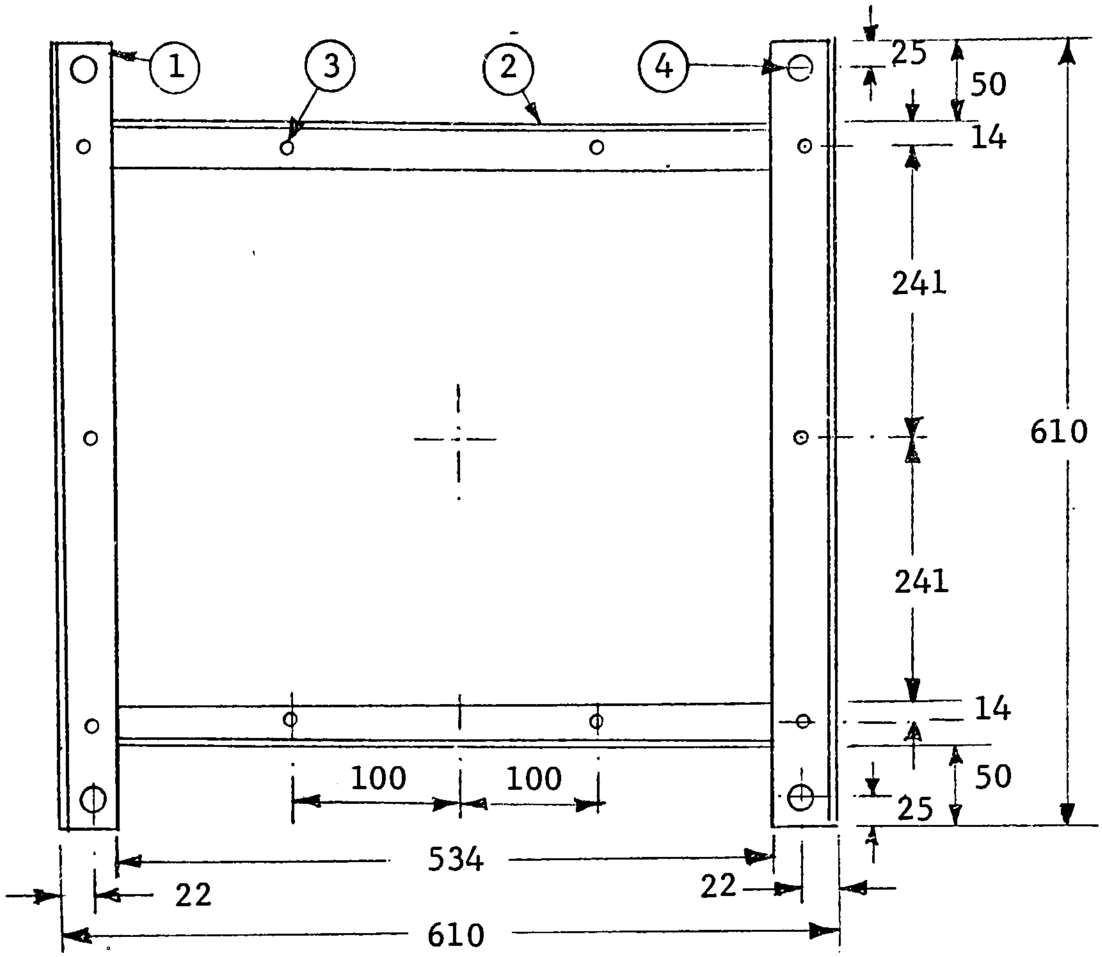


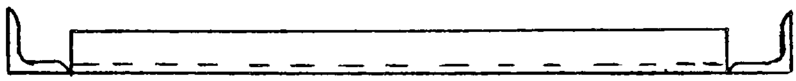
Quartzline Lamp mounting



Terminal Block mounting

Fig.17 Lamp Board





(1) Two 1½" x 1½" x 3/16" angle irons

(2) Two 1¼" x 1¼" x 3/16" angle irons

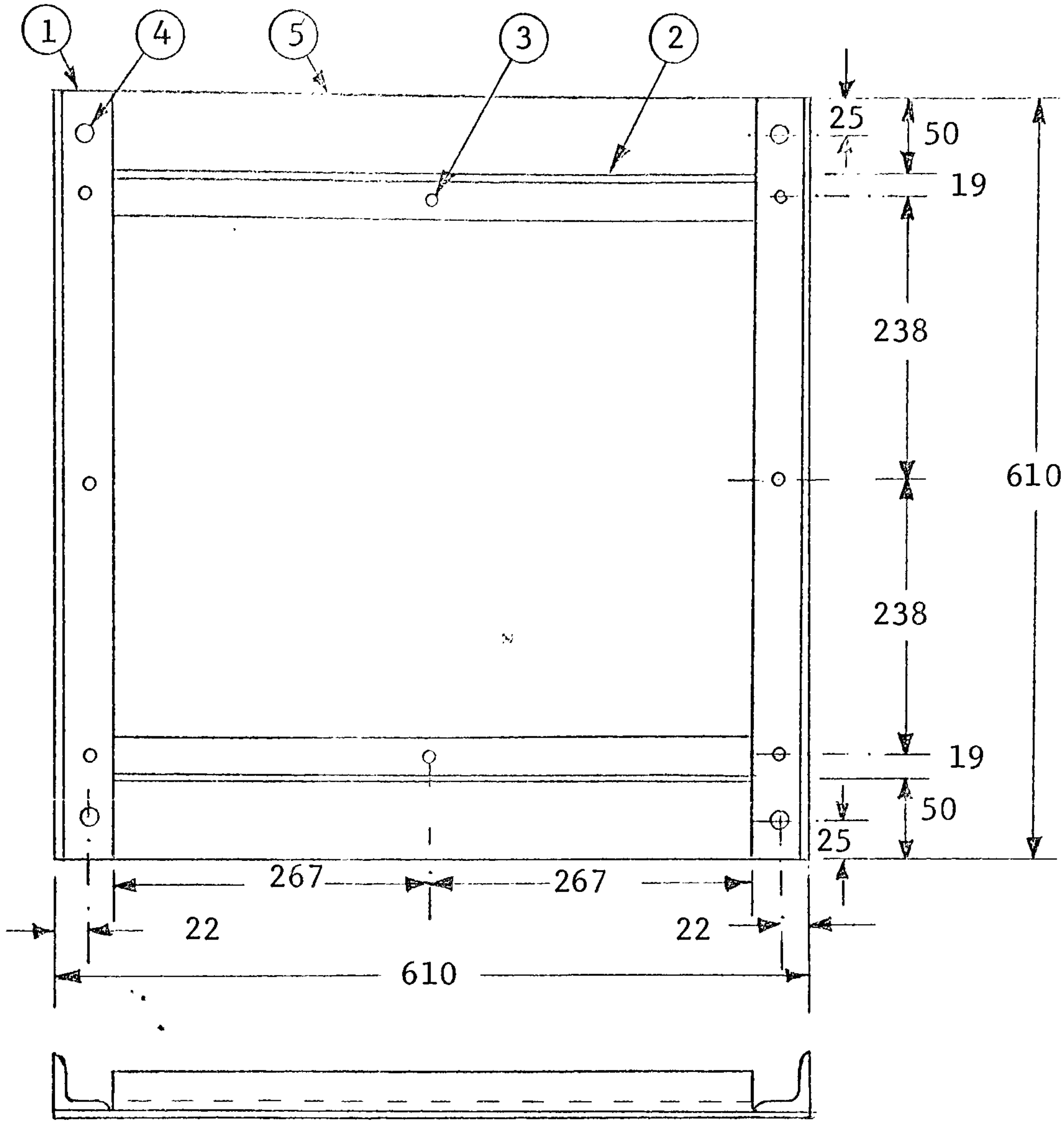
(3) Ten 8-32 tapped holes to secure Lamp board (Fig.17, page 55) to Lamp board frame

(4) Four 21 mm dia. holes to secure Lamp board frame on four 3/4" screw rods

Fig.18 Lamp board frame

REFLECTOR

The area of the reflector as seen by the lens thru the diaphragm was designed to be a circle of diameter z = 164.9 mm, page 48. Therefore, the reflector surface did not have to be larger than a square plate of side about 13 inches, allowing some space for securing the reflector to the main framework. Such a construction would however have meant making a truncated enclosure between the lamp board and the reflector. In order to have the construction as simple as possible, the reflector was also made the same size as the lamp board. A 24 inch x 24 inch galvanized steel sheet 1/32 inch thick was used as the reflector and secured to a framework made of 1½ inch angle irons. The reflector framework was the same as the lamp board framework shown in Fig. 18, page 56. The reflector frame just like the lamp board frame was secured to the same 3/4" screw rods through the holes at the corners and held in position by nuts. Fig. 19, page 58 shows the physical dimensions of the reflector board mounted on the 24" x 24" frame.



1. Two 1½" x 1½" x 3/16" angle irons
2. Two 1¼" x 1¼" x 3/16" angle irons
3. Eight holes tapped 6-32 for securing reflector plate to reflector frame
4. Four holes 21 mm dia for securing reflector frame on four 3/4" screw rods
5. Reflector plate .79 mm thick

Fig.19 Reflector frame

The reflecting surface was designed to be made by application of a suitable paint having good optical properties. The article "Optical sphere paint and a working standard of reflectance" by Grum & Luckey in Applied Optics, Nov.1968 suggests that Eastman white reflectance paint made by Distillation product industries has excellent reflectance properties as far as the percentage of light reflected and stability of the coating are concerned. The reflectance of the coated surface is reported to show very little variation with changes in the wavelength of the incident light. It was this paint that was originally intended to be used for the reflector surface. Correspondence with the manufacturer however revealed that the paint was rather expensive ($ 50.15 a pint). As a result, it was decided, at least as a start, to use the Flat white spray paint made by Pittsburgh paints.

DIAPHRAGM

Because of the extremely small dimensions involved, a workable method of fabricating the diaphragm seemed to be photographic reduction of a drawing of the diaphragm made many times larger than the desired size.

A drawing of the diaphragm with a scale 18:1 was made on an illustration board with a white background. The black areas of the drawing were filled with black ink. The board was held against a wall and illuminated by two General Electric 1000 watt 2400°K studio flood lamps (G.E.Lamp no. IM/PS 52/77). A view camera, Orbit Monorail view camera made by Burke & James Company, with R.I.T. # 107 Ilex lens and No.4 Acme synchro shutter were used so as to get a 1:18 reduction of the object. Magnification $(s'/s) = (1/18)$, and focal length of the lens $f = 254$ mm. Substituting these values in $(1/s) + (1/s') = (1/f)$, $s = 4826$ mm and $s' = 268$ mm.

The camera was arranged so that the lens was approximately 4826 mm from the diaphragm drawing. Time of exposure

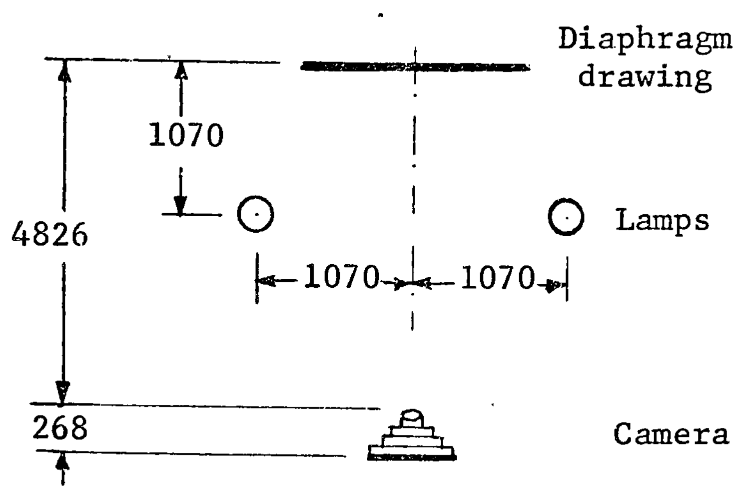


Fig.20 Photographing the diaphragm drawing

Film #	f/	Exposure in sec.	Result
1	22	1	Underexposed
2	16	1	Underexposed
3	11	1	Underexposed
4	8	1	Satisfactory
5	5.6	1	Satisfactory
6	4	1	Overexposed

Table 5: Exposure of diaphragm drawing

was held constant at 1 second, the aperture varied from f/4 thru f/22, and exposures were made. The film used was 3M Company's lithographic film no. 331130-092. The exposed films were processed in 3M Company's Photographic Products division at Rochester, N.Y. according to standard procedure for processing lithographic film under Wratten 1A red safe-light conditions. Fig.20, page 61 shows the arrangement of lamps, drawing and camera, and the results shown in Table 5 on the same page. The purpose of this experiment was to determine the best exposure and aperture for photographing the drawing. From Table 5, page 61, it could be seen that an aperture of f/8 and exposure time of 1 second produced satisfactory results.

The experiment was repeated with the diaphragm drawing, lamps and the camera arranged the same way as in Fig. 20, page 61. As the object distance 4826 mm could not be measured with good accuracy, the camera was moved in steps of 50 mm on either side from the measured distance of 4826 mm, and the drawing photographed at each step. The film used was once again 3M Company's lithographic film, and the films were processed as before.

The processed film was placed in an optical comparator in 3M Company's Photographic Products division for measuring the dimensions of the steps. The comparator could measure the width with an accuracy of 0.001 mm. The width of the twenty-first step in all the film samples were measured and are shown in the upper part of Table 6, page 64. It could be seen that the film samples # 5 and # 6 were the most promising with error less than 0.6 % . The error in the other samples was unacceptably large. The width of all the steps in film samples # 5 and # 6 were measured and are shown in the lower portion of Table 6, page 64. The error in the width of the first few steps in both cases was high, up to 18%, which was unacceptable. The experiment indicated that these steps in the drawing had to be redrawn to closer tolerances to get a more accurate diaphragm.

A completely new drawing was made with dimensions 18 times the actual diaphragm size desired, taking special care to draw the steps, especially the narrower ones, with more accuracy. The drawing was mounted on the film holder of the Graphic arts camera in GAF Graphic arts division, Binghamton, N.Y. A 7 mil polyester base lithographic film, GAFmate P 707 was used to photograph the drawing to 1/18 of its size. The film was developed in a Log-E Processor using GAF LR-3

Film sample	Approx. object distance in mm	Width of 21st step	% error in step width
1	4626	52.034	4.1
2	4676	51.543	3.8
3	4726	50.642	1.3
4	4776	50.796	1.6
5	4826	50.290	0.6
6	4876	49.664	0.7
7	4926	49.396	1.2

Step	Desired	Film #5			Film #6		
	width mm	Actual width mm	Error in mm	Error in %	Actual width mm	Error in mm	Error in %
1	0.500	0.592	+.092	+18.4	0.610	+.110	+22
2	0.629	0.683	+.054	+ 8.5	0.703	+.074	+11.8
3	0.793	0.842	+.049	+ 6.2	0.855	+.062	+ 7.8
4	0.998	1.023	+.025	+ 2.5	1.031	+.033	+ 3.3
5	1.256	1.263	+.007	+ 0.6	1.243	-.013	- 1.0
6	1.581	1.602	+.021	+ 1.3	1.616	+.035	+ 2.2
7	1.991	2.001	+.010	+ 0.5	2.005	+.014	+ 0.7
8	2.506	2.526	+.020	+ 0.8	2.527	+.021	+ 0.8
9	3.155	3.126	-.029	- 0.9	3.168	+.013	+ 0.4
10	3.972	3.972	.000	0.0	3.978	+.006	+ 0.2
11	5.000	5.021	+.021	+ 0.4	5.031	+.031	+ 0.6
12	6.294	6.330	+.036	+ 0.6	6.350	+.056	+ 0.9
13	7.924	7.975	+.051	+ 0.6	8.004	+.080	+ 1.0
14	9.975	10.055	+.080	+ 0.8	10.084	+.109	+ 1.1
15	12.558	12.629	+.071	+ 0.6	12.676	+.118	+ 0.9
16	15.809	15.987	+.178	+ 1.1	15.752	-.057	- 0.4
17	19.902	20.242	+.340	+ 1.7	19.704	-.198	- 1.0
18	25.054	25.223	+.169	+ 0.7	25.319	+.265	+ 1.1
19	31.542	31.816	+.274	+ 0.9	31.831	+.289	+ 0.9
20	39.708	39.935	+.227	+ 0.6	40.094	+.386	+ 1.0
21	50.000	50.290	+.290	+ 0.6	49.664	-.336	- 0.7

Table 6: Width of diaphragm steps

developer. The film with the diaphragm image was put under a microscope capable of measurements with an accuracy of 0.0001 inch or 0.00254 mm. The measurements made are shown in Table 7, page 66. The error in the width of steps or heights was not more than 1.5% anywhere in the diaphragm, and the film could be used as the diaphragm in the instrument.

There were two drawbacks to using the diaphragm on the polyester base. The first was the absorption of light by the polyester base, and the fact that the absorption could vary with time. The second objection was the instability of the diaphragm image on the polyester base. The solution to this problem seemed to be: (a) coat a photo-sensitive emulsion on a suitable glass base and make a contact print with the polyester diaphragm, (b) coat a photo-resist on a suitable glass base and make a contact print with the polyester diaphragm.

Discussion with the concerned department personnel in GAF Corporation at their Photographic products division in Binghamton, N.Y. revealed that coating of silver halide emulsion on glass plate would involve a number of problems,

Step	Desired width mm	Actual width mm	% Error	Actual hght. mm	% Error
1	0.5000	0.5075	+1.49	2.5283	+1.13
2	0.6295	0.6388	+1.47	2.5268	+1.07
3	0.7924	0.8037	+1.42	2.5475	+1.09
4	0.9976	1.0109	+1.33	2.5243	+0.97
5	1.2559	1.2699	+1.12	2.5250	+1.00
6	1.5811	1.5983	+1.09	2.5220	+0.88
7	1.9905	2.0134	+1.15	2.5230	+0.92
8	2.5059	2.5365	+1.22	2.5283	+1.13
9	3.1548	3.1835	+0.91	2.5288	+1.15
10	3.9716	3.9668	-0.12	2.5238	+0.95
11	5.0000	4.9645	-0.71	2.5245	+0.98
12	6.2946	6.2543	-0.64	2.5293	+1.17
13	7.9245	7.9411	+0.21	2.5253	+1.01
14	9.9763	9.9653	-0.11	2.5233	+0.93
15	12.5594	12.5293	-0.24	2.5218	+0.87
16	15.8113	15.7844	-0.17	2.5280	+1.12
17	19.9053	20.0586	+0.77	2.5105	+0.42
18	25.0593	24.9941	-0.26	2.5180	+0.72
19	31.5479	31.4249	-0.39	2.5280	+1.12
20	39.7164	39.5456	-0.43	2.5340	+1.36
21	50.0000	49.8150	-0.37	2.5363	+1.45

Table 7 Width & Height of diaphragm steps

which while being not insurmountable, would necessitate time and work out of proportion with the end result desired. Diazo coated plates were readily available but the opaque areas in the processed plate would not be opaque to normal light but only to ultraviolet light. Under the circumstances, the second method seemed to be the best possible solution for making the diaphragm.

Making the diaphragm with photo-resist

The method employed briefly was to coat a photo-resist on a chrome-plated glass, expose the coated glass in contact with the polyester diaphragm and process the glass plate. The details of making the diaphragm by this method follow.

Plate preparation: The plate used was 2½" x 2½" x 0.060" soda lime glass on which Chromium had been deposited to a layer of 80 nm. The glass plate was first washed in a boiling detergent water and rinsed with filtered deionized water. The rinsed plate was dried by isopropynol vapors in a drying chamber at 90 °C for 10 minutes.

Photo-resist application: The plate was then held by vacuum on a base at the end of a motor shaft and capable of spinning at high speed. A few drops of the positive photo-resist solution GAF PR-102 were deposited on the chrome plate. The motor was then spun at 2500 rpm for twenty seconds to remove excess photo-resist and to have a uniform 1000 nm thick layer of photo-resist on the plate. Ten plates were thus coated. The coated plates were then pre-baked in an oven at 85 °C for ten minutes.

Exposure: The coated plate and the polyester diaphragm were then held in a contact print frame and exposed to ultra-

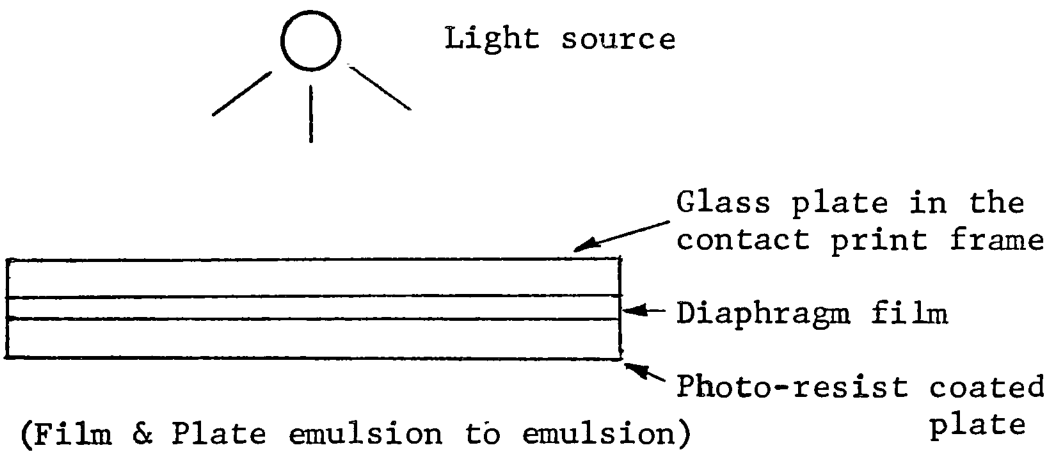


Fig. 21 Imaging diaphragm on photo-resist coated plate

violet light for 90 seconds. Fig.21 above shows the arrangement used in the contact print frame for the exposure.

Development: The exposed plate was developed with GAF

Microline PR Developer D-014 at 27 °C for ten seconds. The plate was then washed in water at a temperature of 27 °C for one minute and then dried in warm air stream.

The plate was etched using Bell & Howell etchant HC 300 at 27 °C for five minutes. The plate was then washed with water. The stripping was then done with DMF and the plate was washed and dried.

The diaphragm plate was then mounted in a diaphragm holder which in turn was mounted in the Lamp board as shown in Fig.17, page 55. The diaphragm could be slid in one direction in the holder and secured by means of six screws. The diaphragm holder in turn could be moved in a direction perpendicular to the direction in which the diaphragm could be moved in the holder. The diaphragm could thus be moved in two mutually perpendicular directions and the center of the diaphragm could be made to coincide with the axis of the instrument. Fig.22, page 70 shows the details of the diaphragm holder.

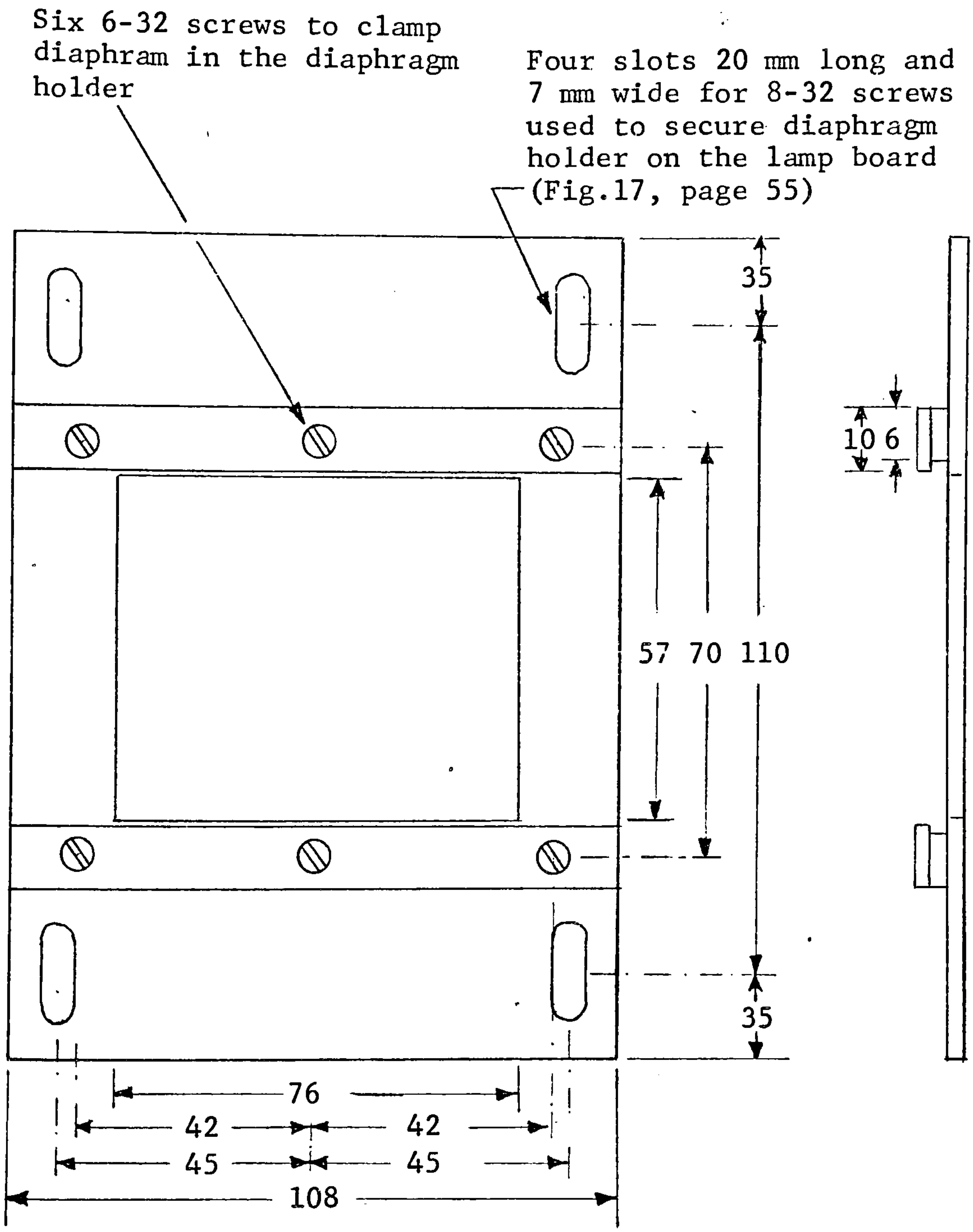


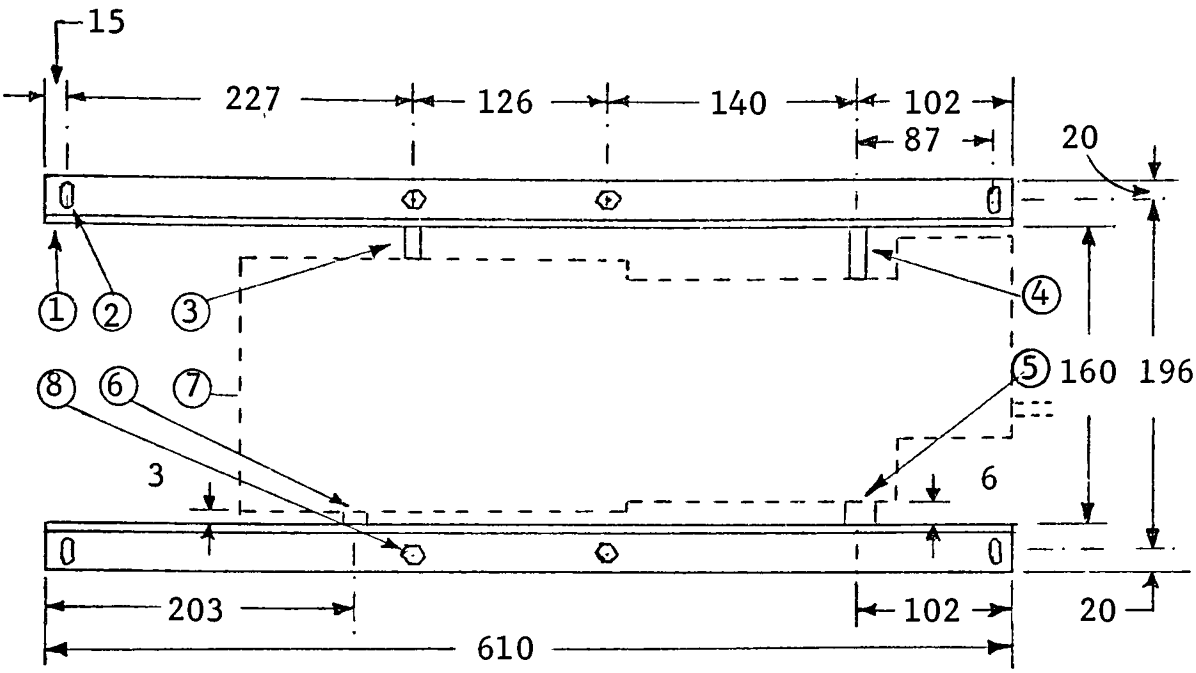
Fig.22 Diaphragm Holder

SHUTTER ASSEMBLY

A 24" x 24" framework made up of 1½" x 1½" x 3/16" angle irons, Fig.18, page 56, as in the case of lamp board and reflector, was used to mount the shutter assembly.

It would have been possible to use a smaller framework between the shutter and the film holder. But there was a disadvantage to this type of construction. The instrument was vertical with the lamp board at the top and the film holder at the bottom. Selection of a smaller cross section for the bottom part would have given rise to a physically unstable arrangement. This would have been aggravated by the fact that the heaviest component of the instrument, the shutter assembly, would be located in the upper half of the instrument. A large base for the instrument therefore was essential to insure a stable arrangement. The shutter assembly was therefore mounted on a framework of the same size as the rest of the components.

Fig.23 on page 72 shows the physical dimensions of the framework used to mount the shutter assembly, and Fig.24 on



(1) Two $1\frac{1}{4}$" x $1\frac{1}{4}$" x 3/16" angle irons

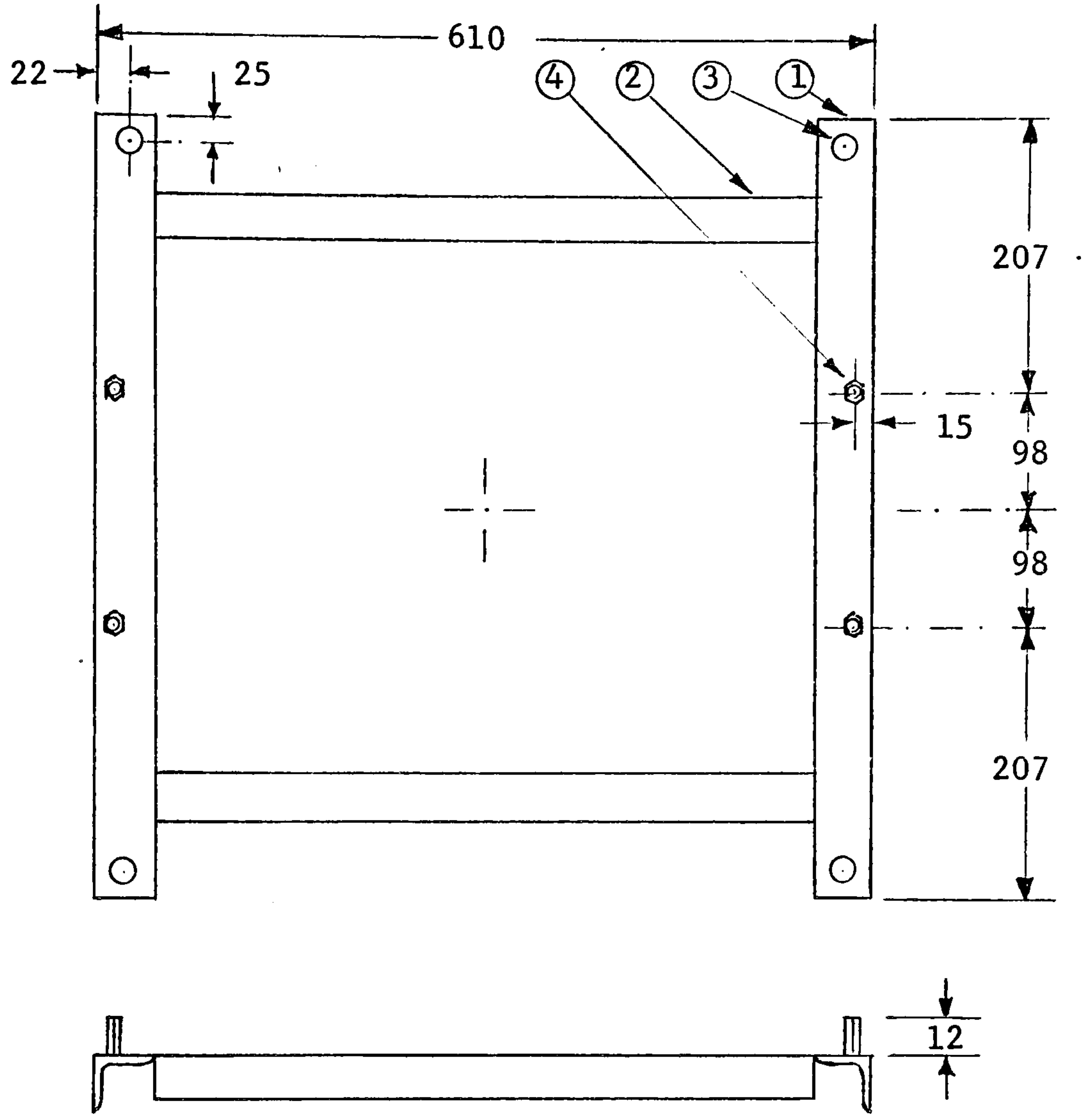
(2) Four slots 22 mm long and 9 mm wide for aligning the Shutter frame on the Main shutter frame (Fig.24, page 73)

(3) (4) (5) (6) Spacers 22 mm, 27 mm, 8 mm and 3 mm thick respectively to fit the Shutter assembly on the Shutter frame. Four 1/4-20 bolts pass thru the $1\frac{1}{4}$" x $1\frac{1}{4}$" x 3/16" angle irons and spacers and fit in the tapped holes of the Shutter assembly.

(7) Shutter assembly

(8) Four 1/4-20 nuts 39 mm long secured to the Shutter frame by four bolts to mount the Lens holder (Fig. 25, page 76).

Fig.23 Shutter frame



① Two $1\frac{1}{2}$" x $1\frac{1}{2}$" x 3/16" angle irons

② Two $1\frac{1}{4}$" x $1\frac{1}{4}$" x 3/16" angle irons

③ Four 21 mm dia. holes to secure Main shutter frame on four 3/4" screw rods

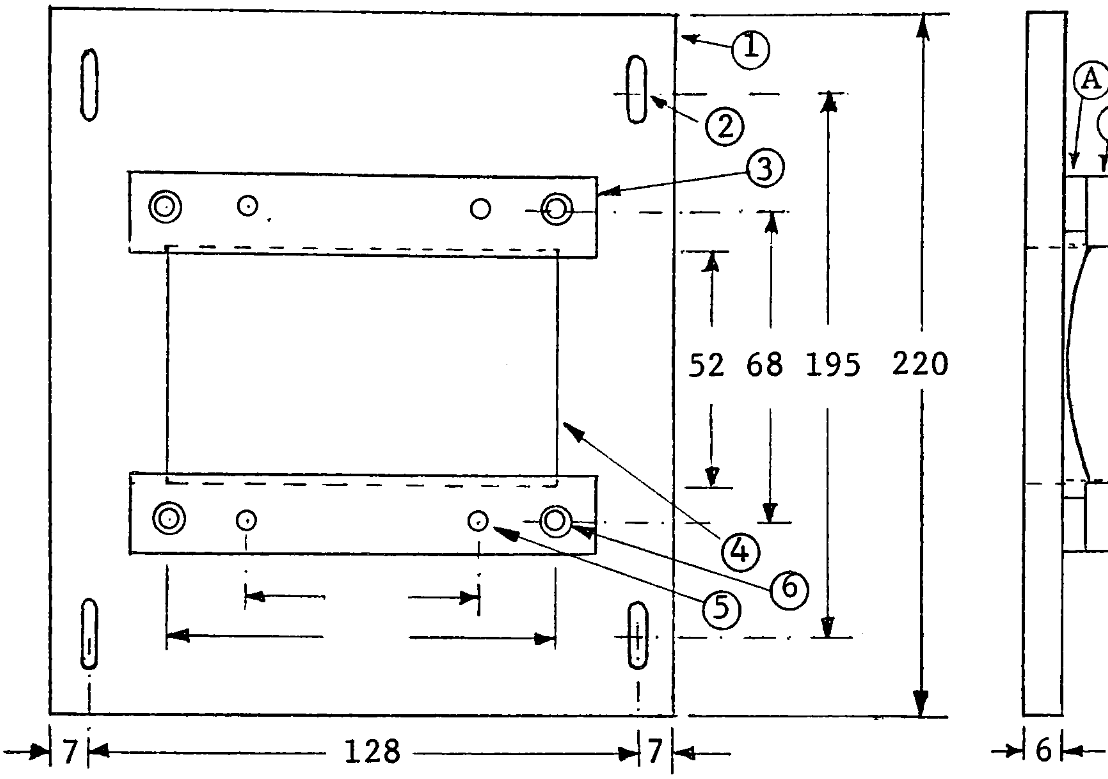
④ Four 1/4-20 hexagonal nuts secured to Main shutter frame by bolts on which the Shutter frame (Fig.23, page 72) is placed, adjusted and secured.

Fig.24 Main shutter frame

page 73 shows the main frame on which the shutter assembly framework was mounted.

LENS HOLDER

A lens holder was made to mount the lens with provision to move the lens in a direction perpendicular to the axis of the instrument. The lens holder itself could be moved in a direction perpendicular to the axis of the instrument and the direction of lens movement. This arrangement was made so that the lens could be centered in the instrument accurately. Instead of using a separate 24" x 24" frame for the lens holder, the framework for the shutter assembly was made so that the lens could also be mounted on it. Fig.25 on page 76 shows the details of the lens holder, and Fig.23 on page 72 shows the shutter assembly framework on which the lens holder was also mounted.



① Lens holder plate which mounts on the Shutter frame (Fig.23, page 72). ② Four slots 10 mm wide, 20 mm long to move the lens holder plate in the y direction. ③ Lens holder arrangement consisting of Ⓐ Ⓑ & Ⓒ to enable movement of the lens holder in the x direction. ④ Opening for the lens, 100 mm x 52 mm. ⑤ Four 6-32 tapped holes to secure the lens guide, parts Ⓐ & Ⓑ to the lens holder plate. ⑥ Four 6-32 tapped holes to secure the lens in place.

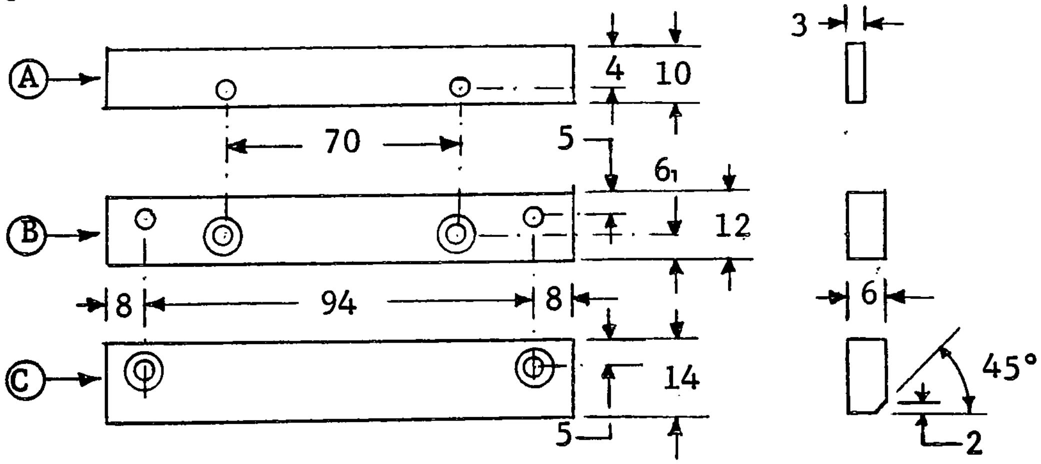


Fig.25 Lens holder

TEST FILM STRIP HOLDER

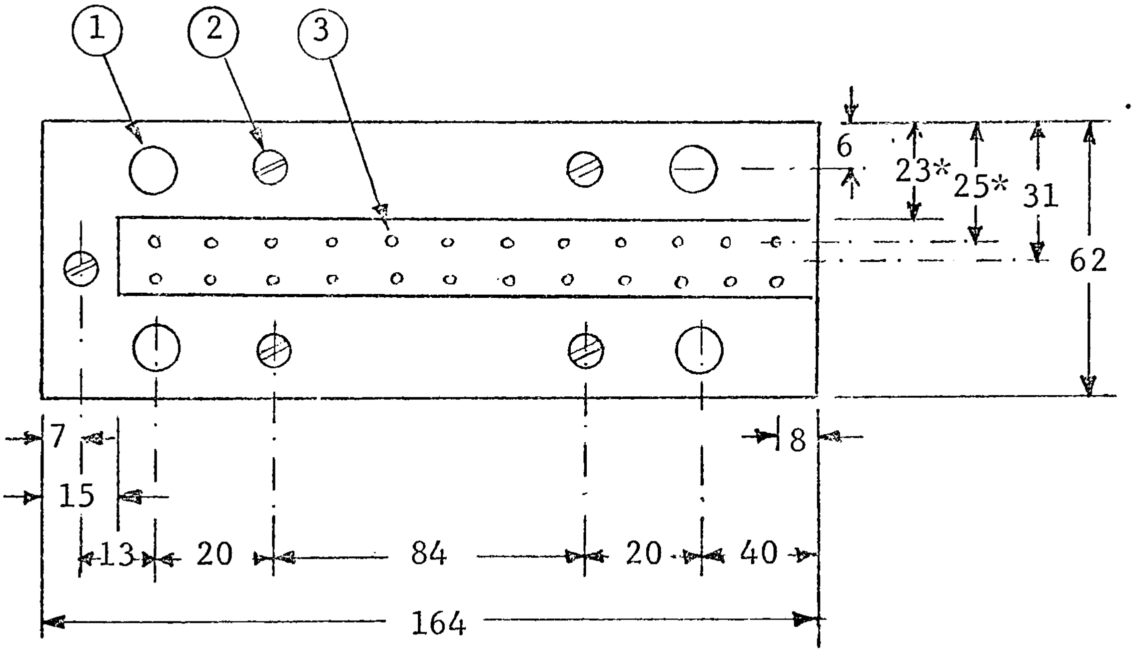
The test film strip holder was designed to accept film strip 8 mm or 16 mm wide. The part holding the film strip was made separate and secured to the film strip holder frame by means of four screws. Two plates, one with a slot for insertion of 8 mm wide film strip and another with a slot for 16 mm wide film strip were made to the same outside and mounting dimensions so that either of them could be screwed on to the film holder depending on the width of the test film strip to be used. Interchanging of the plates involves only removing four screws, positioning the plate for the desired film strip width and tightening the four screws.

Small holes of 1.5 mm diameter were drilled on the two plates for the 8 mm and 16 mm frames to enable the test film strip to be held in place by vacuum during exposure. As all parts of the film holder were painted with flat black paint, there was no possibility of light shining thru the film and the small holes and reflecting back to the film. Also, the holes were drilled near the edges of the slot on which the test film strip would be held. Any difference in density that could possibly occur because of the presence of holes would not matter as the density measurements of the processed test film strip in a densitometer would normally be confined to the center region of the film strip. Fig.26 on page 80 shows the details of the test film strip holder.

The film holder, Fig.26, page 80, was mounted on a Film holder base by means of four screws as shown in Fig. 27, page 81. The film holder base was fitted on hinges to the Film holder frame so that the Film holder base could be swung open for insertion and removal of the test film strip. A magnetic catch was fitted on the Film holder frame to hold the Film holder in position when it was swung shut. Fig.28, page 82 shows the details of the Film holder frame and the magnetic catch. A brass male elbow was screwed to the back of the Film holder base, and 1/4" O.D. polyethylene tubing was provided for connection to a vacuum pump.

The film holder frame, Fig.28, page 82, was secured to a 24" x 24" Main film holder frame as shown in Fig.29, page 83. The Main film holder frame was completely covered by a plate except for the opening in the center for the hinged Film holder base. The details of the Main film holder frame cover are shown in Fig. 30, page 84.

(1) Four holes 12 mm dia. to secure film holder to Film holder base (Fig.27, page 81) by screws
(2) Five 8-32 screws to secure the top plate to film holder
(3) Fifty-four holes 1.5 mm dia, 5 mm apart for subjecting the film back to vacuum



* These are the dimensions for Film holder for testing 16 mm wide film strips. For 35 mm wide film strips all dimensions remain same except the two marked with asterisk: 23* dimension becomes 13 and 25* becomes 19.

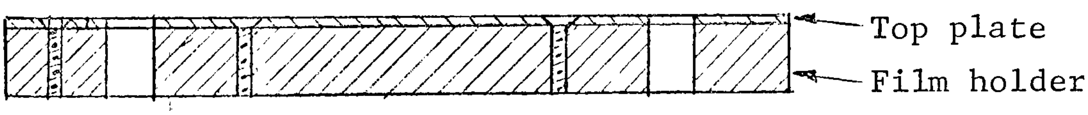
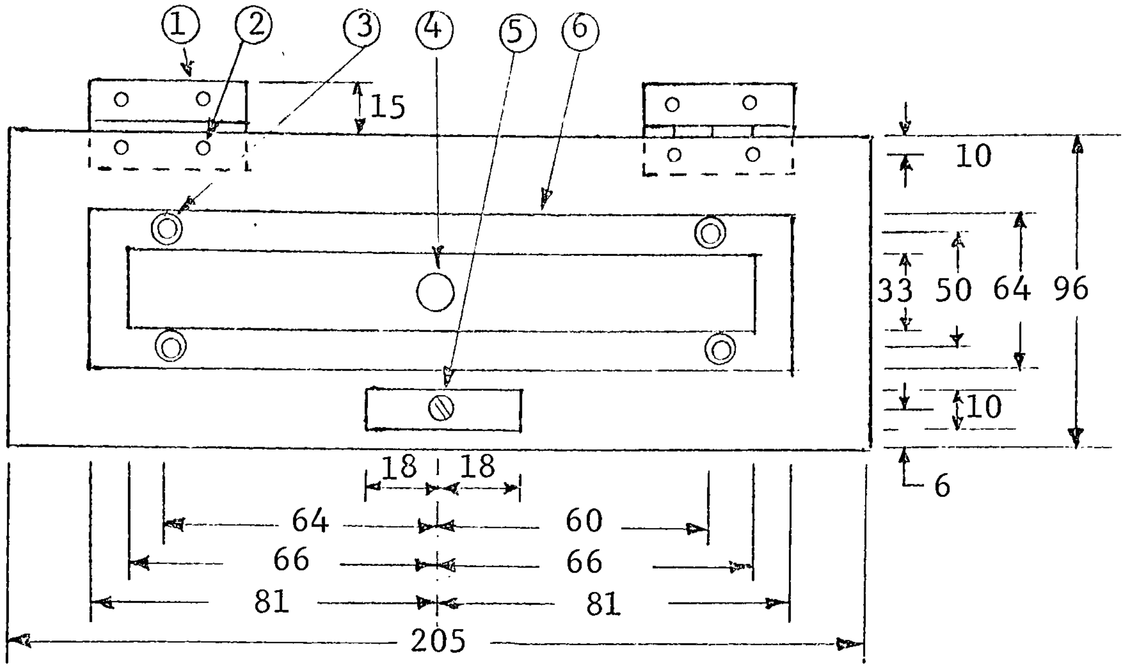


Fig.26 Film holder



1. Two brass hinges to secure film holder base to Film holder frame (Fig.28, page 82)
2. Four 6-32 tapped holes to secure the hinges to film holder base
3. Four 7 mm dia holes in gasket and four 1/4-20 tapped holes in Film holder base to secure film holder to film holder base
4. 1/8 NPT hole for vacuum connection

5. 8-32 screw & tapped hole in film holder base to secure magnetic catch tab to film holder base
6. Rubber gasket on which the film holder is positioned

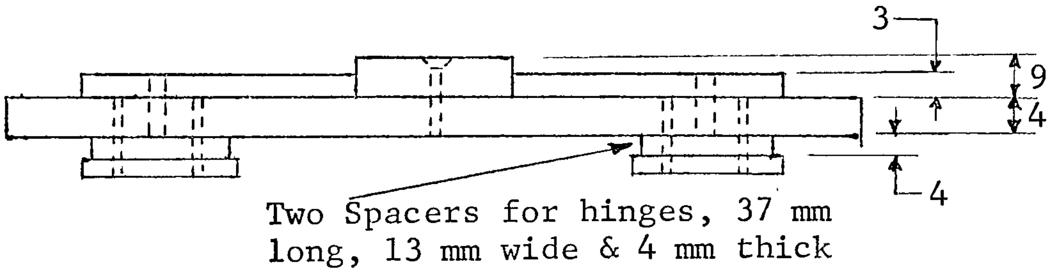
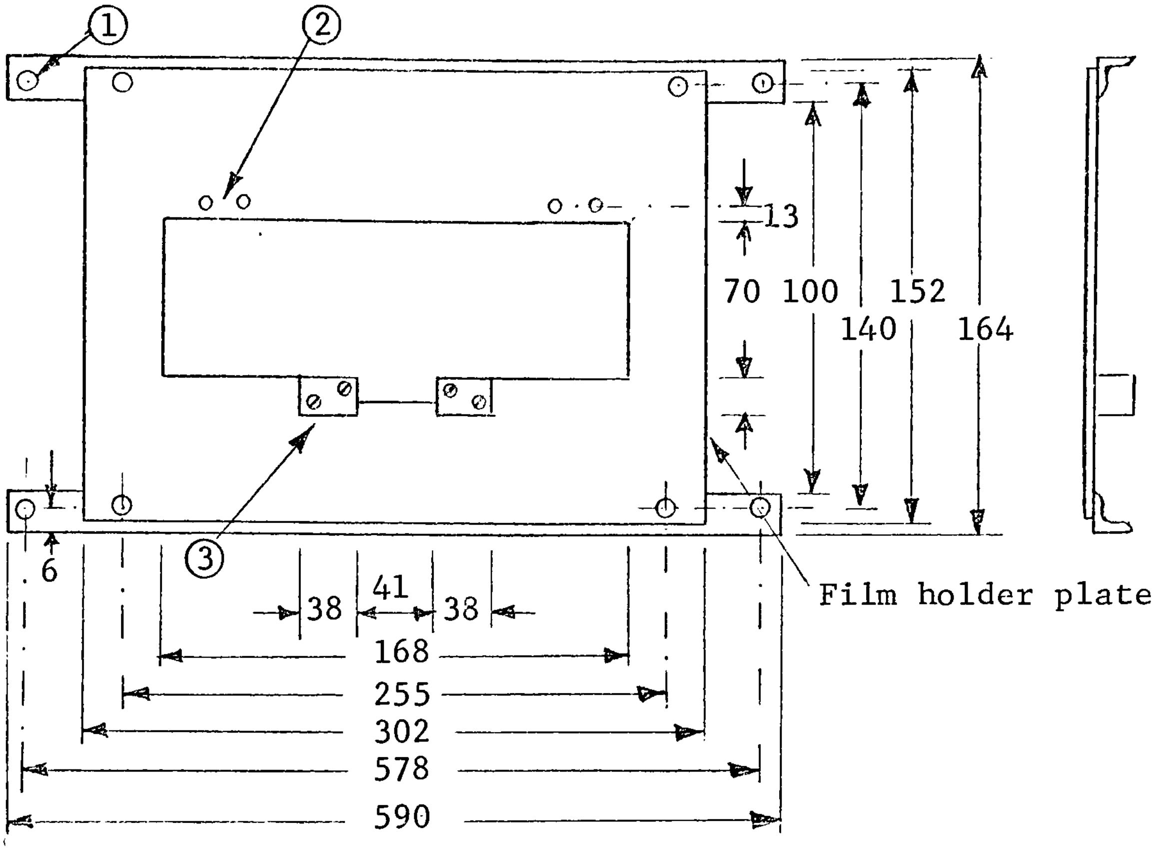
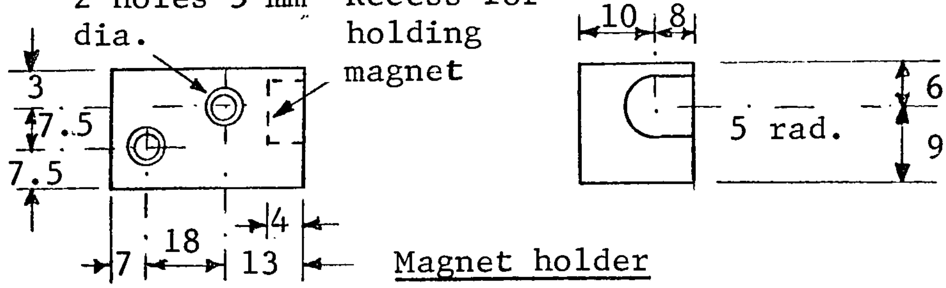


Fig.27 Film holder base

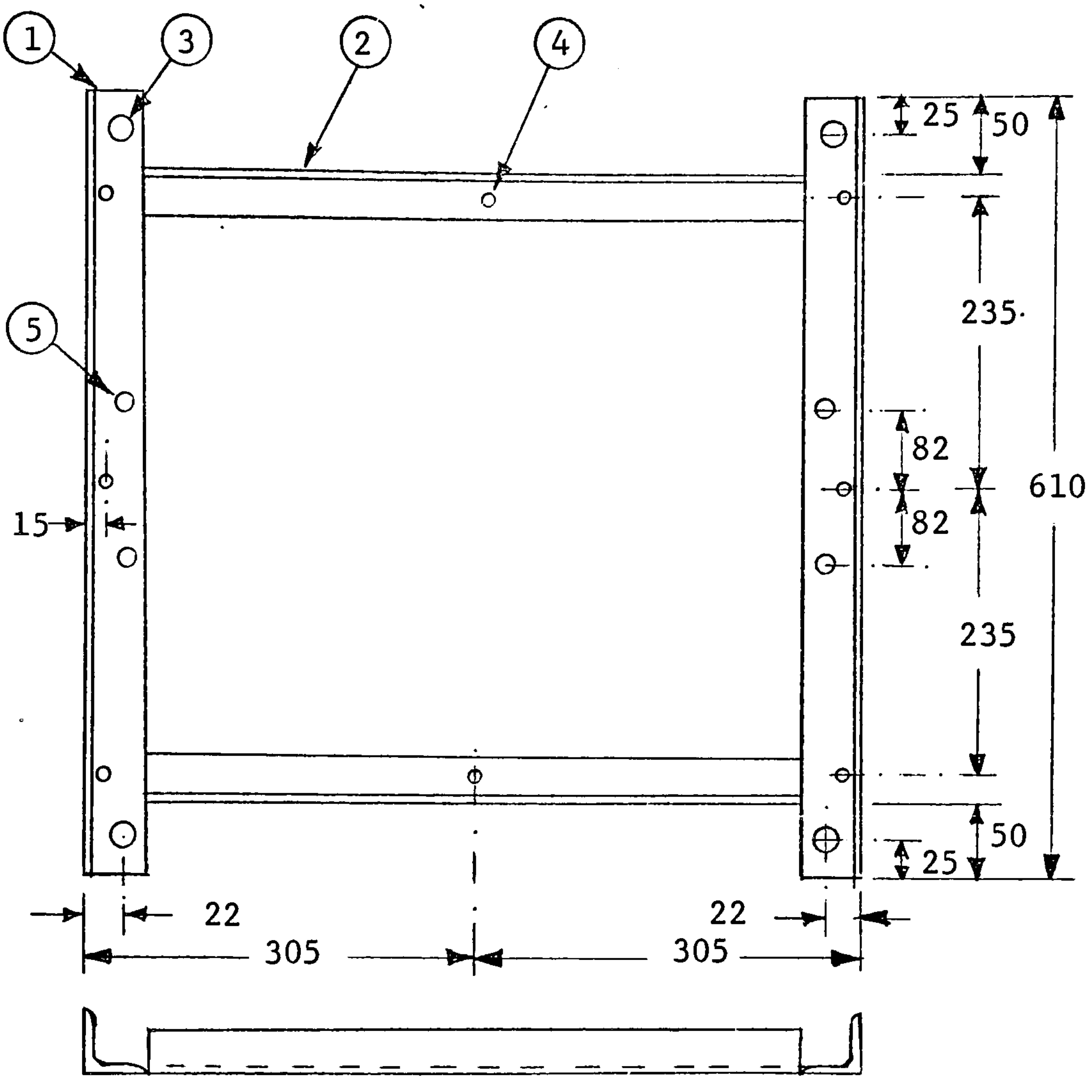


① Four 11 mm dia. holes for mounting the film holder frame on the Main film holder frame (Fig.29, page 83).
② Four 6-32 tapped holes for securing the hinges of the film holder (Fig.27, page 81) to the film holder frame.
③ Two magnet holders for holding the magnet, 10 mm dia x 50 mm long, to keep the Film holder in position during exposure (details below).



Magnet holder

Fig.28 Film holder frame



1 Two 1½" x 1½" x 3/16" angle irons

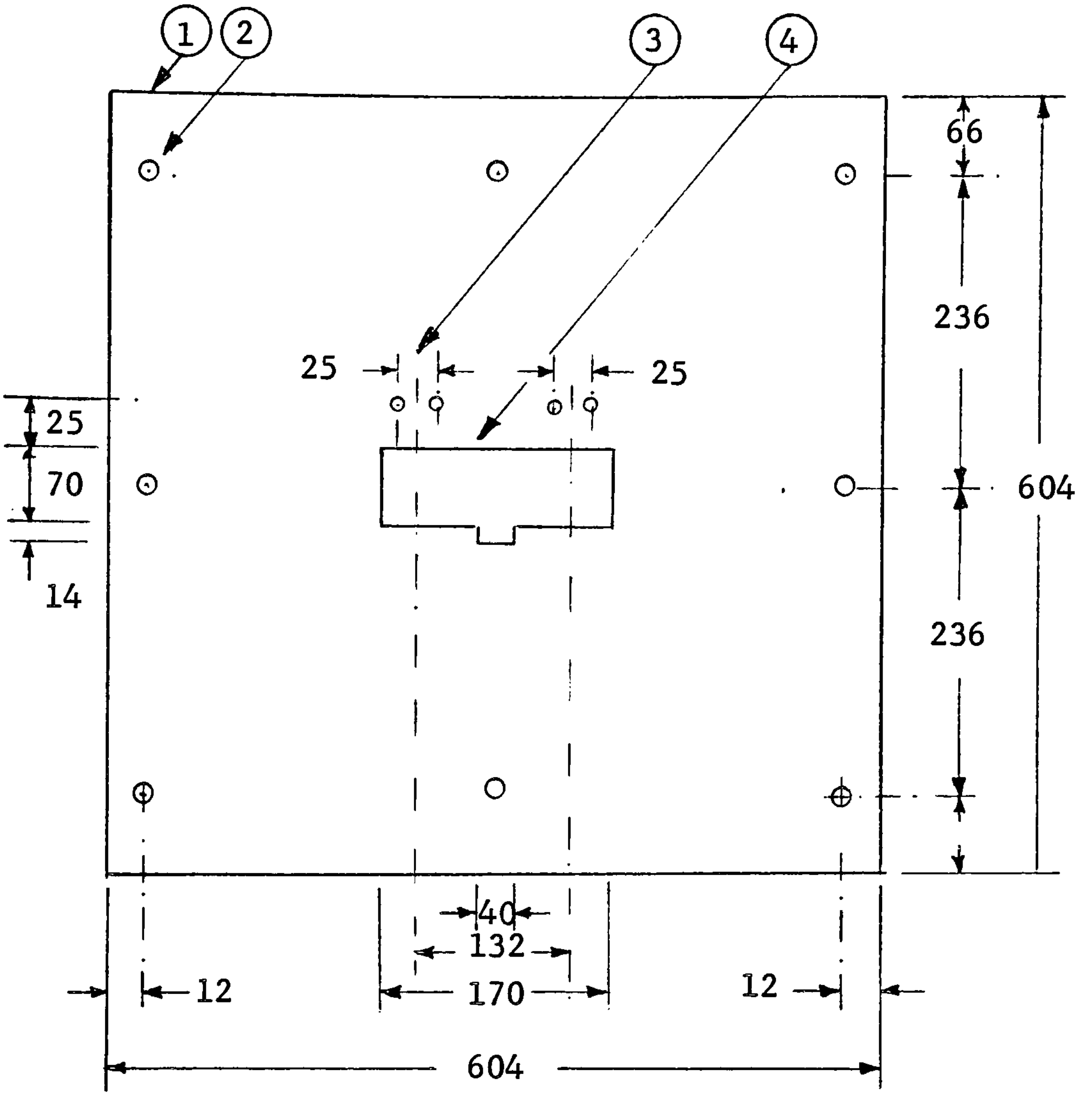
2 Two 1¼" x 1¼" x 3/16" angle irons

3 Four 21 mm dia. holes to secure main film holder frame on four 3/4" screw rods

4 Eight 8-32 tapped holes to secure Main film holder plate (Fig.30, page 84) to main film holder

5 Four 5/16 - 18 tapped holes to secure Film holder frame (Fig.28, page 82) to main film holder frame.

Fig.29 Main film holder frame



(1) Main film holder plate 0.8 mm thick

(2) Eight 5 mm holes to secure main film holder plate to Main film holder frame (Fig.29, page 83)

(3) Four 3 mm holes for the hinges in the Film holder frame (Fig.28, page 82) to pass through main film holder plate and be secured to Main film holder frame (Fig.29, page 83)

(4) Opening for the Film holder base (Fig. 27, page 81)

Fig. 30 Main Film holder plate

COMPONENT ASSEMBLY

The foregoing sections described the details of construction of the component subassemblies, namely, Lamp board, Reflector, Diaphragm, Shutter assembly, Lens holder and Test film strip holder. The subassemblies were all in a 24" x 24" framework as shown in Fig.18, page 56.

Four 3/4" screw rods were passed through the holes in the four corners of each component framework. Eight nuts were used to secure each framework on the screw rods. Distance between component frameworks were adjusted so that the distance between the components were according to dimensions shown in Fig.15, page 50. Each component framework was then adjusted so that it was level on two mutually perpendicular directions to insure that the components were normal to the axis of the instrument. Once the individual component frameworks were levelled and adjusted, the component itself was adjusted so that its center coincided with the axis of the instrument.

The four sides of the instrument formed by the screw

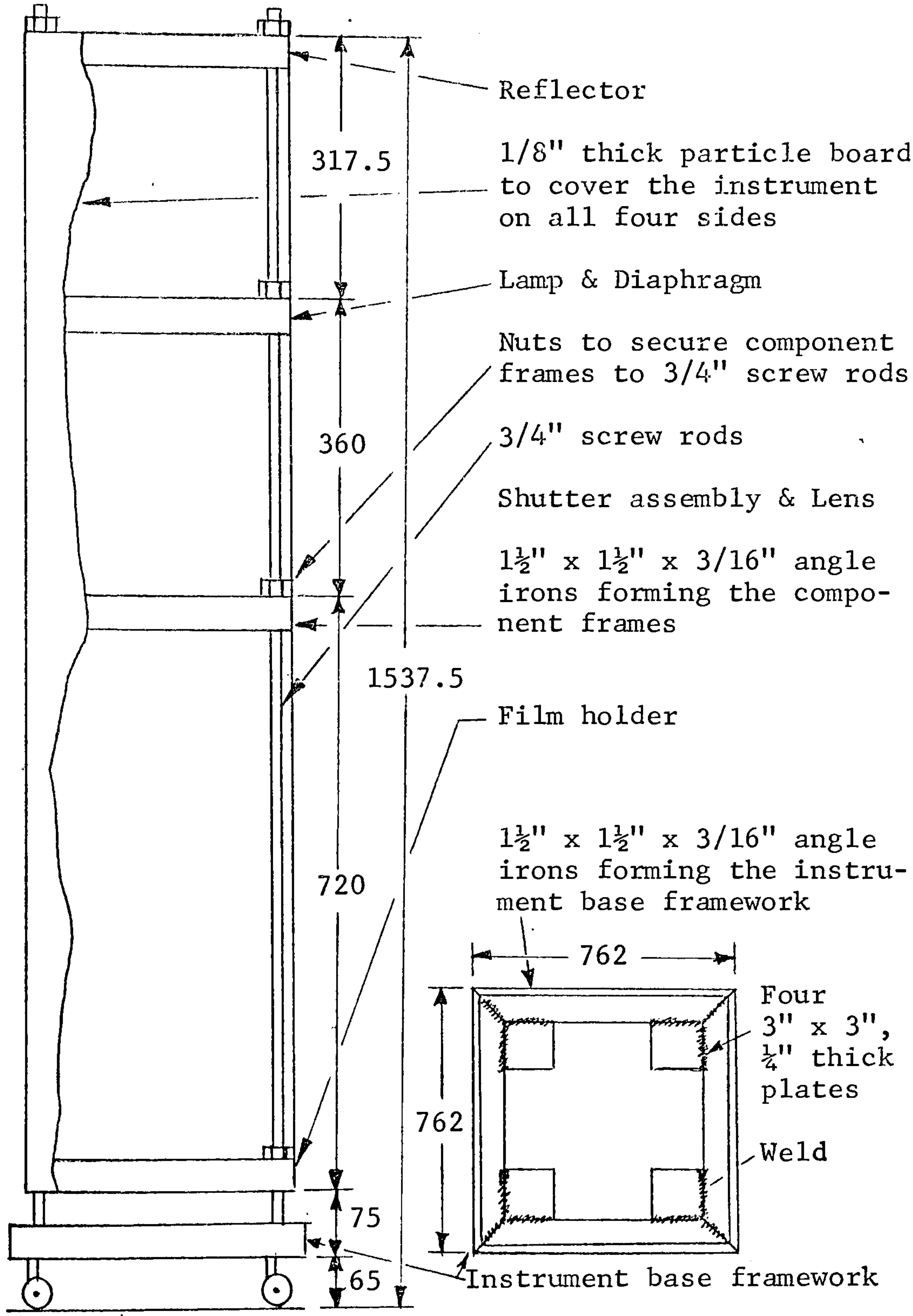


Fig.31 Sensitometer

rods were then covered by 1/8" thick particle board completely except for holes behind the cooling fan to exhaust the hot air generated by the burning of lamps. These holes were staggered so that the light from the lamps could not shine through them; at the same time, the holes permitted the hot air inside the instrument to be exhausted to outside. The whole inside of the instrument except the reflector board was spray painted with flat black paint to minimize stray light from reflections affecting the instrument. The instrument assembly was then mounted on an Instrument base framework equipped with casters so that the instrument could be moved about easily.

The assembly of the component frameworks on the screw rods to form the Sensitometer is shown in Fig.31, page 86.

PXA LAMP POWER SUPPLY

The chassis containing the components necessary for operating the PXA lamps was designed to fit in the Power supply cabinet which already housed the power supply unit for the Quartzline lamps and exposure chassis. The front of the PXA chassis forming part of the Power supply cabinet is shown in Fig.32, page 89.

The circuit for the tungsten lamp power supply was modified so that at any time only one set of lamps - PXA lamps or tungsten lamps - could be lit.

The design and layout of the components for the PXA lamp circuitry took into consideration the fact that voltage at the time of starting the lamps could be very high. Ignition cables for automobile engines were used in the part of circuit where the high voltages would appear. Low resistance electrical contacts were used to handle the high peak currents. The seal for the lamps cannot withstand temperature higher than 200 °C. The lamps in the

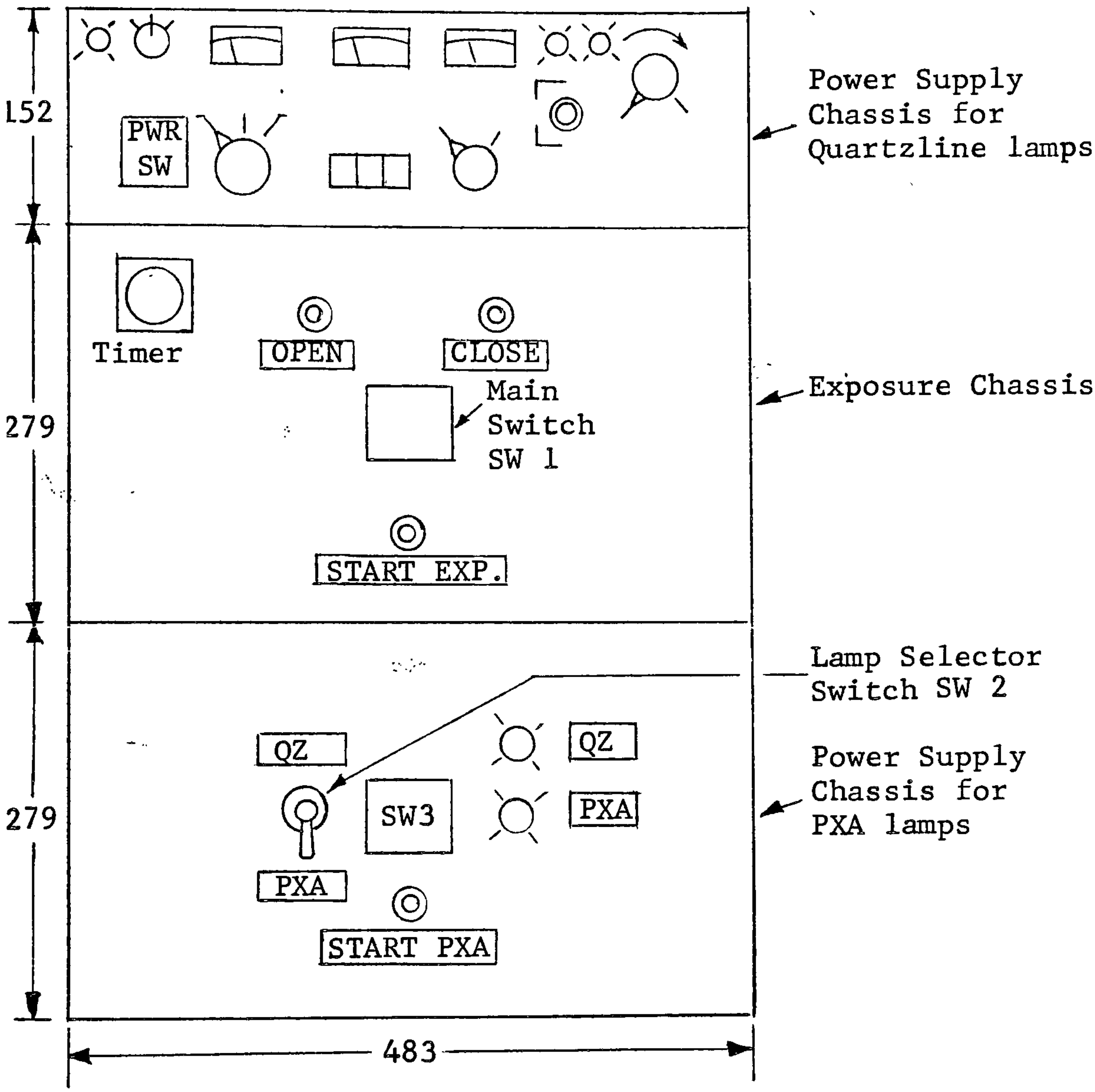


Fig.32 Lamp Power Supply & Exposure Cabinet

lamp board were mounted on the metal sheet forming the lamp board with metal clips to insure dissipation of heat. The exhaust fan provided above the lamp ventilated the hot air in the lamp board region and provided the cooling necessary for the lamps.

The instrument was enclosed by panels on all its four sides so that the operator of the instrument will not be exposed to the ultraviolet light from the PXA lamps which could cause erythemal effect on eyes and skin. The lamps should not be viewed with the naked eye because of the harmful effects. The electric power should be turned on only when the four side panels are in place to insure protection from electric shocks by accidental contact with live terminals on the lamp board.

Working of the PXA lamps

The schematic wiring diagram for the PXA lamp power supply is shown in Fig.33, page 91. When the PXA lamps are used, the lamp selector switch SW 2 will be in the position shown in figure. Turning on the switch SW 3 in the Power supply chassis for the PXA lamps makes the 240 volts a.c. available across the primary of the Auto transformer.

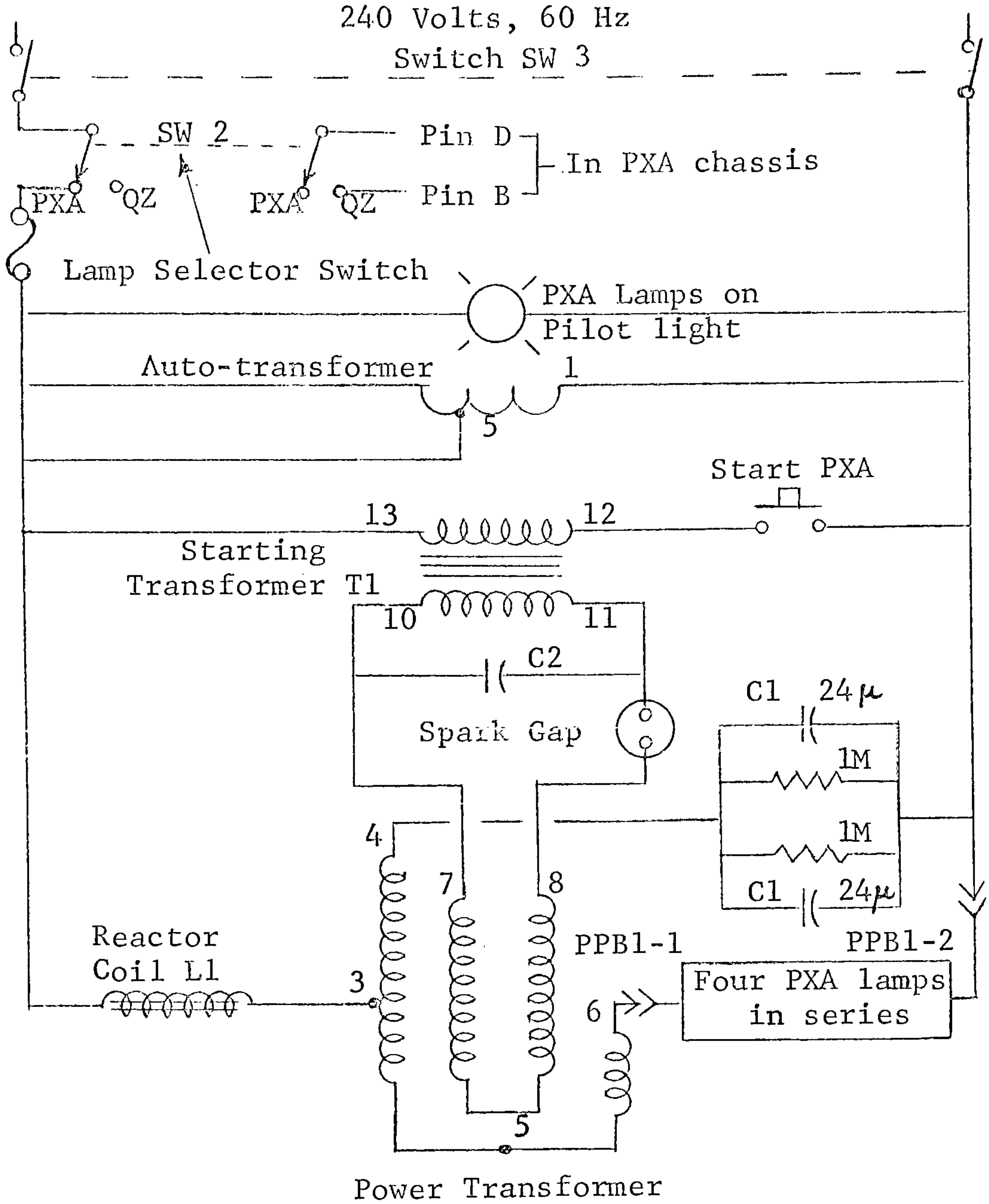


Fig.33 PXA Lamps Schematic Wiring diagram

Depressing the Start PXA push button switch will apply 240 volts to the primary of the Starting Transformer T1. The Power transformer is in turn energized, and the PXA lamps provide light output pulse of approximately 1/1000 second duration every half cycle of the mains frequency 60 Hz. The starting circuit is required only to light up the lamps initially, and the Start PXA push button switch should be released after about two seconds when the lamps have acquired full brilliance. The lamps could be turned off by turning off the switch SW3.

CHASSIS INTERCONNECTIONS

Wiring between the chassis was done using cable connector pins and sockets to facilitate removal of individual chassis for inspection and trouble-shooting. Fig.34, page 94 shows the details of the interconnection among the three chassis, Quartzline lamp Power supply chassis, Exposure chassis and PXA lamp Power supply chassis and also connections to the lamps and shutter assembly.

Two cable connector sockets were installed in the instrument framework between the Lamp board and Shutter frame and all connections from the Power supply units and Exposure unit to the lamps and shutter assembly were made through cable connector pins which mated these two sockets. This enabled the instrument to be easily disconnected from the Power supply cabinet.

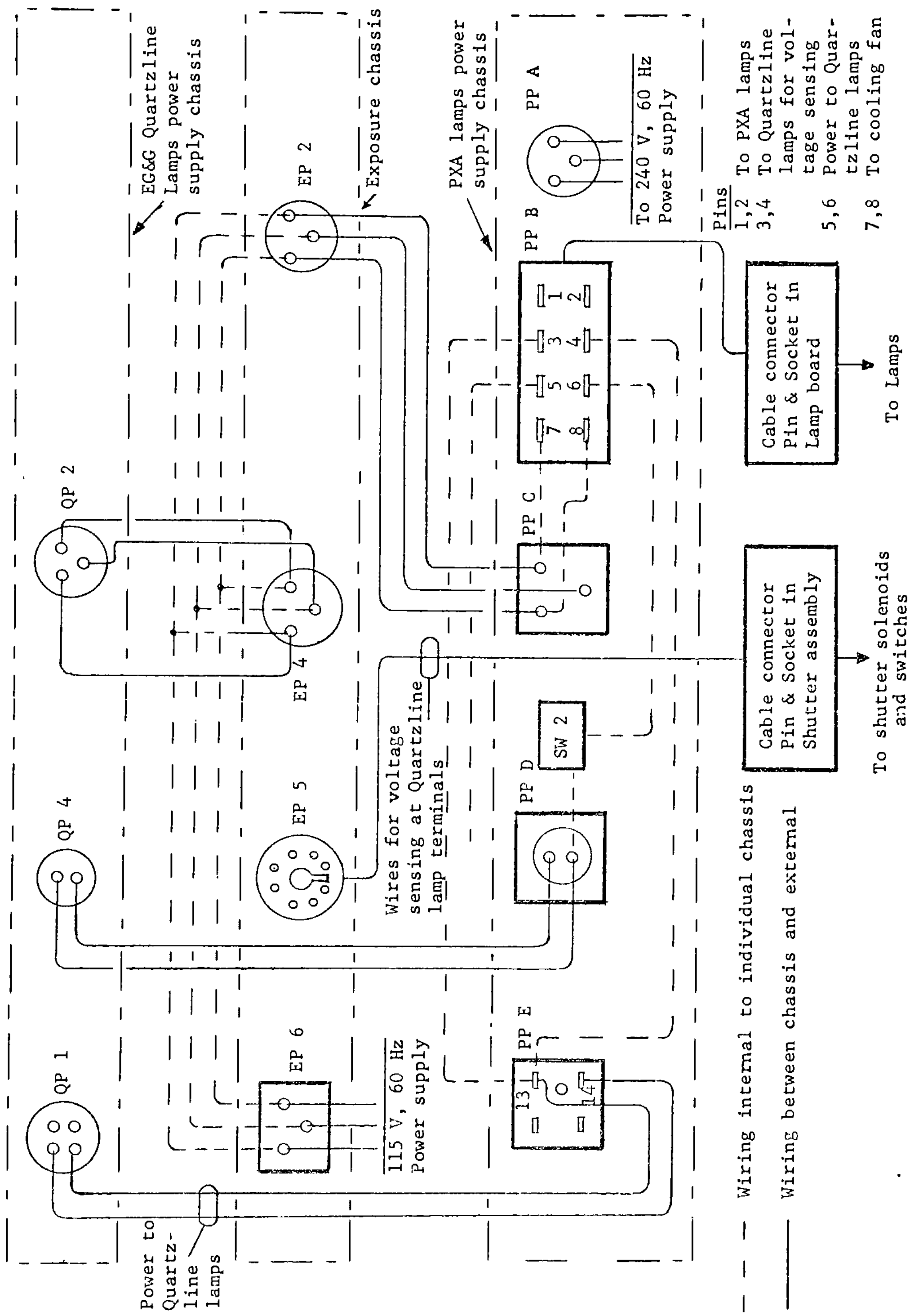


Fig.34 Chassis Interconnections

PART 4

OPERATION OF SENSITOMETER

GENERAL

This part will describe the operation of the Sensitometer and associated equipment, and the method to be followed for exposing a test film strip. Though the salient points of the equipment manufacturers' recommendations have been included in the procedure for operating the lamps, it is recommended that the instrument operator studies the manufacturers' literature on the lamps and power supply equipment for a fuller understanding.

OPERATION OF PXA LAMPS

1 Turn the switch SW1 on in the Exposure chassis.

2 Turn the Lamp selector switch SW2 in the PXA lamp power supply chassis to "PXA".

3 Depress the "Start PXA" push button switch for about two seconds and release.

4 Allow about ten minutes for the circuits to achieve stability.

5 Set the exposure time on the Timer in the Exposure chassis and lock the setting.

6 Swing open the film holder. Insure that the Film holder is the correct one for the film strip (16 or 35 mm) to be used.

7 Under safelight conditions, take out a sample of film strip, 16 mm x 140 mm or 35 mm x 140 mm, and place it in the slot of the film holder. Use of gloves to avoid smudging of the film strips is recommended. With two

fingers holding the edge of the film, start the vacuum pump. As the suction created pulls the film strip against the film holder, smoothen out the film strip to insure that the film strip is held flat on the film holder.

8 Swing the film holder upwards and insure that the magnetic catch holds it in position.

9 Momentarily press the "Start Exp" push button switch in the Exposure chassis.

10 After the set exposure time elapses, the shutter is automatically closed. The sound of closing and resetting of the shutter is unmistakable.

11 Stop the vacuum pump.

12 Swing open the film holder. Withdraw the film strip and store it in a light tight envelope or box for processing.

13 To turn off the PXA lamps, turn off the switch SW3 in the PXA lamp power supply chassis. This turns off the lamps, but the cooling fan will still be on.

14 After about ten minutes, turn off the switch SW1 in the Exposure chassis which turns off the power to the

cooling fan and exposure chassis.

Caution

1 The PXA lamps operate with high voltage on its terminals that remain on even after the power is turned off due to a charged capacitor in the power supply. To avoid electrical shock, any exposed metallic parts or electrical connection should not be touched unless they are disconnected from the power supply and proved to have no voltage by a voltmeter connected between the part and ground.

2 The PXA lamp emits short wave ultraviolet radiation that can be harmful to human eyes or unprotected skin. To guard against direct or reflected radiation, ultraviolet absorbing materials such as glass, clothing or other suitable protective materials should be used.

3 Lamp operation may be accompanied by sparking at switches, relays and socket contacts, and corona discharge or flashovers from the high voltage circuits. This instrument should not be used in atmospheres containing explosive or flammable dust or vapors.

4 Operation of the PXA lamps with fingerprints or

grease on the surface may cause devitrification of the quartz. If the lamp surface becomes dirty or has been touched, it should be cleaned by washing first with a swab moistened with pure acetone and then with another swab wetted with distilled water. It should then be carefully dried with a clean cloth or cotton.

5 Life of the PXA lamps is affected more by the starting of the lamps rather than the duration for which they are lit. The more starts per burning hour of the lamps, the shorter the lamp life.

OPERATION OF TUNGSTEN LAMPS

1 Turn the switch SW1 on in the Exposure chassis.

2 Turn the Lamp selector switch SW2 in the PXA lamp power supply chassis to "QZ".

3 Insure that the following switches in the EG&G power supply for the quartzline lamps are in the OFF position: AC POWER switch, Meter lamps Switch, Current Control Switch (fully counterclockwise is the OFF position), Output switch (Center position is the OFF position).

4 The patch cables are connected in the rear jumpers of the power supply unit to provide 30 volts across each of the four quartzline lamps. Insure that the patch cable connections have not been changed. They should be: Patch cable 1 from R to 1Y, Patch cable 2 from 1B to 3Y, and Patch cable 3 from 3B to W.

5 Set the Volts F.S. range switch to 300 volts.

6 Set the Amp F.S. range switch to 10 amp.

7 Set the Current select switches to the desired current value, which is 6.6 amperes for the quartzline lamps.

8 Place the AC Power switch in the quartzline lamp power supply unit to ON position. PWR and STBY lamps light.

9 Adjust for desired meter lamp brilliance with METER LAMPS switch.

10 Place OUTPUT switch (momentary contact) to ON. STBY lamp goes off, OPER lamp lights. CURRENT meter will indicate a small initial current. Rotate CURRENT CONTROL slowly clockwise until ampere reading on CURRENT meter approximates the setting of CURRENT SELECT switch. Set the meter reading slightly higher.

11 Allow ten seconds for CONTROL MONITOR meter to reach the green balance area.

12 Observe CONTROL MONITOR meter. If indicator is in the blue region (INCREASE), increase CURRENT CONTROL until indicator is within green region (OPERATE). If indicator is within red region (DECREASE), decrease CURRENT CONTROL until indicator is within green region (OPERATE). For best operation, the CURRENT CONTROL should be in the upper 1/3

region of its range when the CONTROL MONITOR indicator is in the green OPERATE area.

12 The lamps are now in operation and will after lamp warmup, remain stable throughout their operating period.

13 Set the exposure time on the Timer in the Exposure chassis and lock the setting.

14 Swing open the film holder. Insure that the Film holder is the correct one for the film strip (16 or 35 mm) to be used.

15 Under safelight conditions, take out a sample of film strip, 16 mm x 140 mm or 35 mm x 140 mm, and place it in the slot of the film holder. Use of gloves to avoid smudging of the film strips is recommended. With two fingers holding the edge of the film, start the vacuum pump. As the suction created pulls the film strip against the film holder, smoothen out the film strip to insure that the film strip is held flat on the film holder.

16 wing the film holder upwards and insure that the magnetic catch holds it in position.

17 Momentarily press the "Start Exp" push button switch

in the Exposure chassis.

18 After the set exposure time elapses, the shutter is automatically closed. The sound of closing and resetting of the shutter is unmistakable.

19 Stop the vacuum pump.

20 Swing open the film holder. Withdraw the film strip and store it in a light tight envelope or box for processing.

21 If for any reason, standby operation is desired, reduce CURRENT CONTROL to OFF slowly for maximum lamp life. Then place OUTPUT switch to OFF. This operation will automatically remove power from the light in the Lamp board, but retain the Power supply in the ready condition. Before operation can be resumed, CURRENT CONTROL must be returned to OFF, the detent position.

22 Upon completion of operation, reduce CURRENT CONTROL to OFF, and place the OUTPUT switch to OFF position.

23 Allow about ten minutes for the lamps to cool. Then turn off the switch SW1 in the Exposure chassis which turns off the power to the cooling fan and exposure chassis.

Caution

1 Any metallic part or electrical connection in the lamp board should not be touched unless it is disconnected from the power supply and proved to have no voltage by a voltmeter connected between the part and the ground.

2 This instrument should not be used in atmospheres containing explosive or flammable dust or vapors.

3 Careless or rough handling of the lamps should be avoided. Abrasions and scratches could result in shattering of the lamp.

4 The lamps should not be operated at more than 30 volts or at a current more than 6.6 amperes.

5 Though the enclosure for the lamp filament in the Quartzline lamps filters out the ultraviolet radiation, direct viewing of the lamp with unprotected eye from a close distance for a prolonged time should be avoided to minimize the harmful effect of the radiation.

6 Operation of the Quartzline lamps with fingerprints or grease on the surface may result in reduced performance and shortened service life. If the envelope becomes dirty

or has been touched, it should be cleaned by washing first with a swab moistened with pure acetone and then with another swab wetted with distilled water. It should then be carefully dried with a clean cloth or cotton.

OPERATION OF SHUTTER

The shutter mechanism is actuated by the controls in the Exposure chassis of the Power supply cabinet. Fig.35 on page 108 shows the circuit diagram for the operation of the shutter. The sequence of operations for exposing a test film strip is as follows.

1 Turn the switch SW1 on in the Exposure chassis. D.C. power is available to shutter solenoid circuits and A.C. power is available at one end of the Exposure Start push button switch.

2 Set the Lamp selector switch SW2 to PXA or QZ as desired, and bring the lamps to full stable brilliance by following the steps outlined in page 97 for PXA lamps and pages 101 through 103 for the Quartzline lamps.

3 Set the desired exposure time on the timer in the Exposure chassis and lock the setting.

4 Insert the test film strip in the Film holder as described in pages 97 and 98 for PXA lamp use and page 103

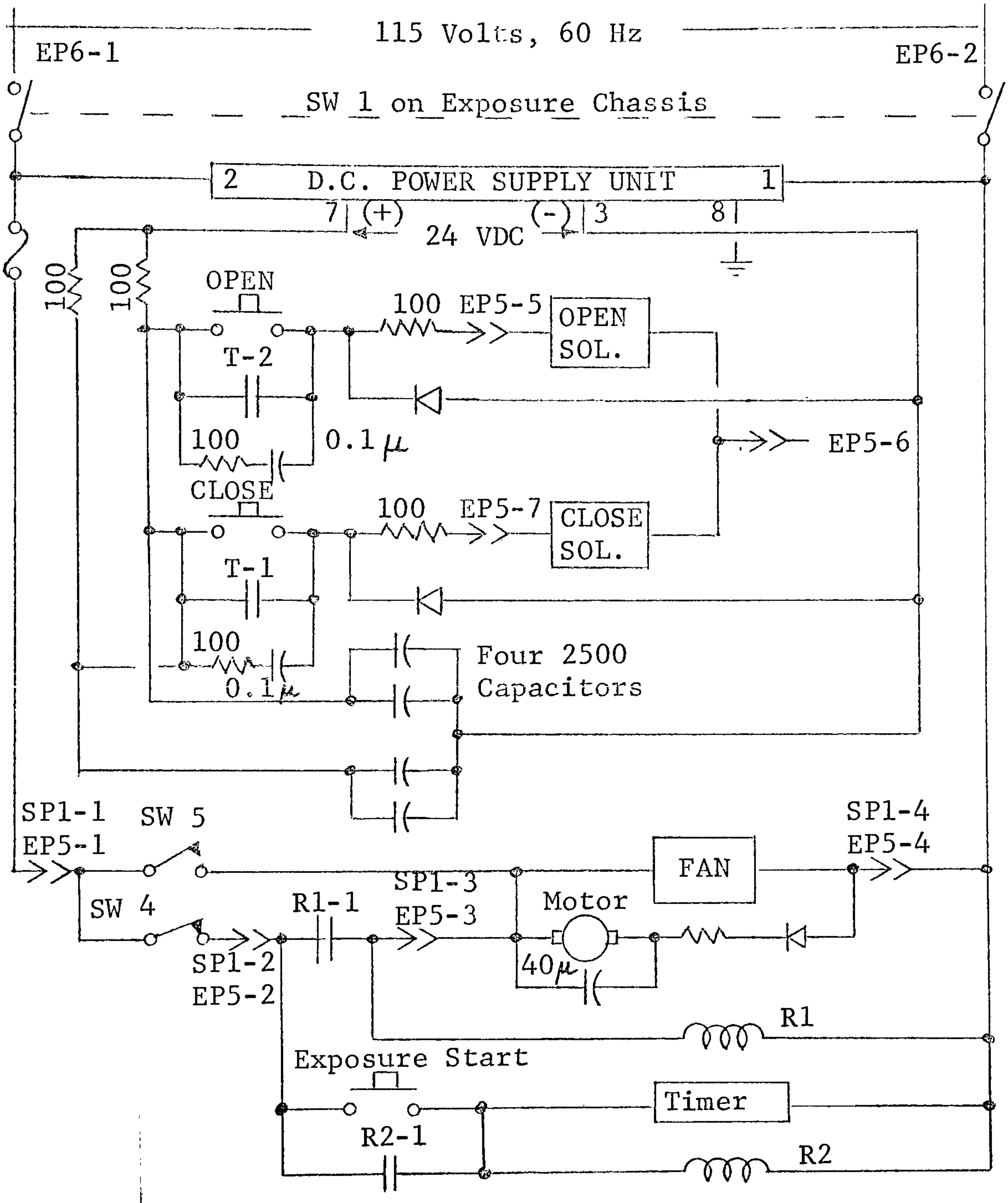


Fig. 35 Exposure Unit - Schematic wiring diagram

for Quartzline lamp use.

5 Momentarily press the Exposure Start push button switch. Relay R2 is energized and is held on through its own normally open contact R2-1. Timer clutch is energized and Timer is on. Simultaneously, the timer contact T-1 opens and T-2 closes causing the Close solenoid to become inactive and energizing the Open solenoid. The shutter plate held on by the Open solenoid armature is released and the film strip is exposed to the light source.

After the set time is elapsed, the timer contact T-2 opens and T-1 closes causing the Open solenoid to become inactive and energizing the Close solenoid. The shutter plate held on by the Close solenoid armature is released and the light is cut off from the film strip. At the end of its travel, the shutter plate held on by the Close solenoid armature till then momentarily closes the switch SW5. This causes the Shutter motor to run. Simultaneously, the momentary closure of switch SW5 causes the relay R1 to energize. Relay contact R1-1 closes and provides a holding circuit for the relay R1 and the Shutter motor through the closed contact of switch SW4. The Shutter motor pushes both the plates of the shutter - one held by the Open solenoid armature and the other by Close solenoid armature - back to their normal position. During this time, as the openings in the two plates of the shutter are staggered, no light is admitted to the film. The plate normally held by the Open solenoid armature at the end of its travel is held back by the de-energized Open solenoid armature. The shutter plate normally held by the Close solenoid armature goes a slight distance past the Close solenoid armature and momentarily opens the switch SW4. This cuts off the power to Shutter motor and relay R1 and the holding circuit. The shutter motor stops. The shutter plate normally held by the Close solenoid armature retracts and is held by the armature of the de-energized Close solenoid. The shutter is reset and ready for the next exposure.

The opening and closing of the shutter can also be done manually. The Open push button switch should be kept pressed during the entire exposure period desired. The Open push button switch should be released at the end of exposure. Though the shutter will shut off the light falling on the film strip at this time, it is necessary to reset the shutter by momentarily pressing the Close button.

COMPONENTS FROM 3M CO.

Following is the list of components and equipment sent by 3M Company, St. Paul, Minnesota to Rochester Institute of Technology, Rochester, New York, and used to construct the Sensitometer.

1 Shutter Assembly

2 Cylindrical Achromat lens, f = 240 mm

3 Lamp Power supply unit, EG&G Model 590-11 for the Quartzline lamps

4 Exposure Chassis

5 Power supply cabinet containing Quartzline Lamp power supply and Exposure chassis with provision for adding a PXA lamp Power supply chassis

6 Four G.E. Quartzline lamps, Model Q 6.6 A/T4/CL, 200 watt

7 Eight Quartzline lamp sockets

8 Four G.E. Pulsed Xenon Arc lamps, PXA-43, 300 watts max.

9 Twenty fuse clips for mounting PXA lamps

10 Auto Transformer, G.E. Model 9T56Y3901, 1.9 KVA, Input 210-250 V, Output 240 V for PXA Power supply

11 Starting Transformer, G.E. Model 9T65Y1084 for PXA lamp Power supply

12 Reactor coil, G.E. Model 9T65Y1086 for PXA lamp Power supply

13 Spark gap, G.E. Model SG-6 for PXA lamp Power supply

14 Two Power capacitors, 24 μfd, 300 VDC with 1 MΩ 1/2 watt resistor connected in parallel for PXA lamp Power supply

15 Starting circuit Capacitor, 0.05 μfd, 3000 VDC for PXA lamp Power supply

PART 5

CONCLUSIONS

FINDINGS

The Sensitometer and the Power supply cabinet were taken to Rochester Institute of Technology and commissioned on June 21, 1974. The information gathered are presented below.

1 The Tungsten lamps and the EG&G Power supply unit worked satisfactorily.

2 The Shutter mechanism in conjunction with the Exposure timer worked properly.

3 The vacuum back for the Film holder was tested at GAF Corporation workshop by connecting a vacuum pump to the Film holder. The results were satisfactory.

4 When the shutter was open, bands of different illumination varying in gradation from one end to the other were observed at the image plane.

5 The PXA lamps presented a problem. By oversight, the four PXA lamps were connected in parallel rather than

in series. Because of this, only one or two lamps lit up when the lamp start push button switch was depressed. It was not possible to get all the four lamps to light up. An examination of the PXA lamps Schematic wiring diagram, Fig.33, page 91 revealed the reason for the malfunction. In a circuit with four parallel-connected PXA lamps, once one lamp lit up, the voltage across its terminals dropped to a low value from the high value the lamp had before it started conducting. This low voltage present across the other lamps would not be high enough to start the lamps. Unless all the lamps started conducting exactly at the same instant which is very unlikely, it would not be possible to have all the lamps light up.

FUTURE WORK

1 The four PXA lamps should be connected in series and their performance assessed.

2 Adjustments of distances between the components should be made to get a sharp image of correct size at the film holder. Centering of the components along the instrument axis should be done.

3 The illumination at the film holder was only visually examined. The illumination at each band should be measured to verify theoretical predictions.

4 Data must be generated for changes in illumination at the film holder plane with changes in the setting of the aperture. Experiments must be conducted with different films using exposure duration and aperture settings as parameters.

5 The high grade reflectance paint made by Eastman Kodak could be coated on the reflector surface for better results.